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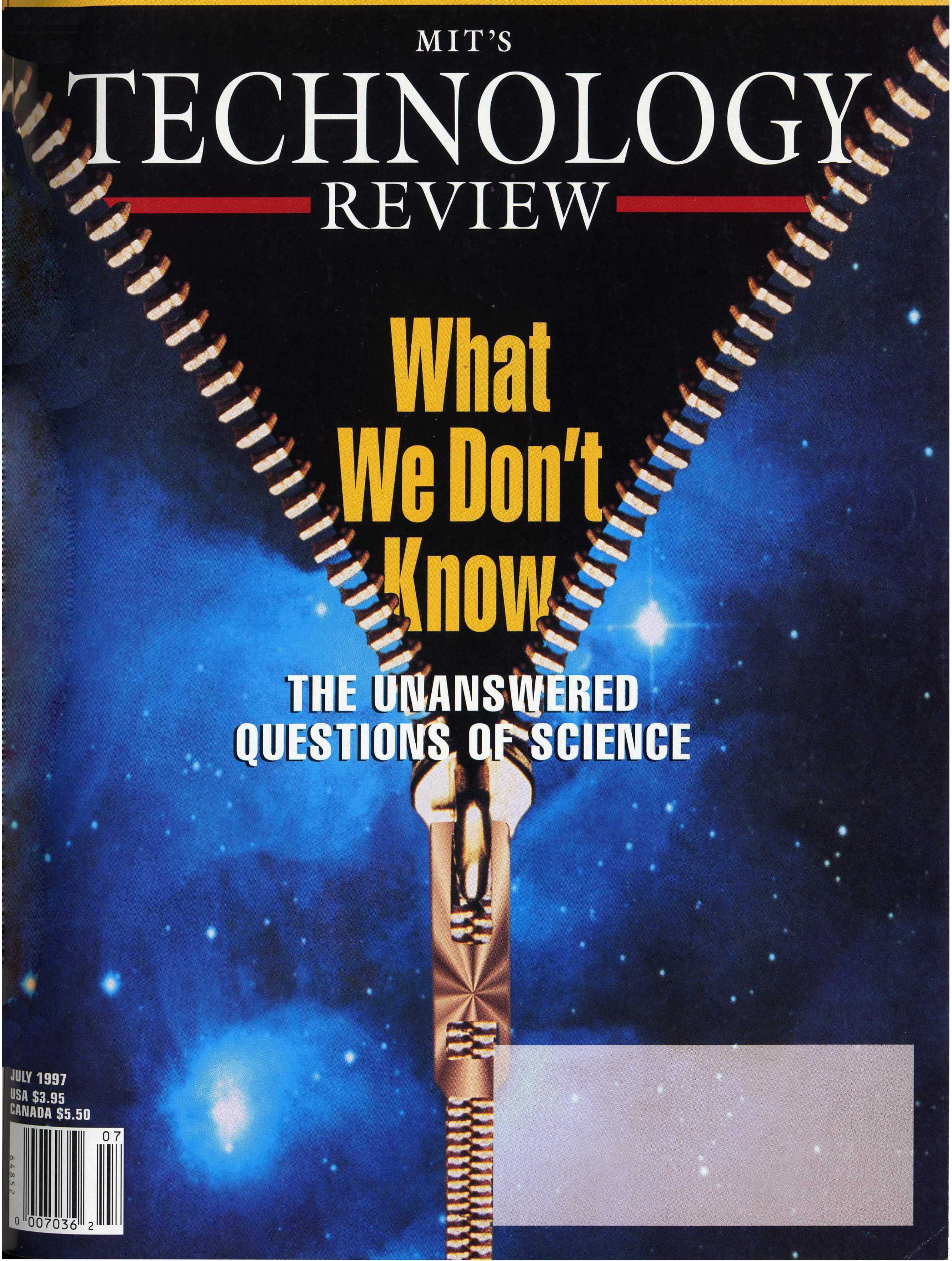

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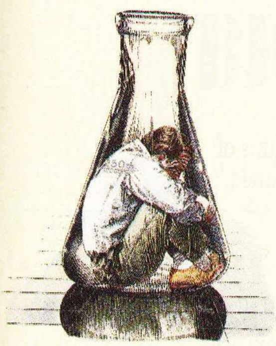

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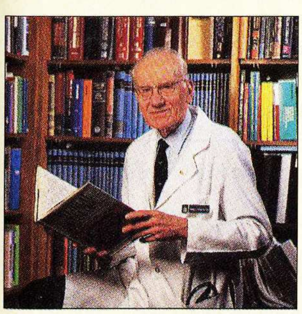

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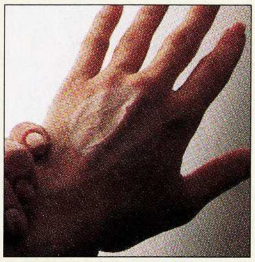

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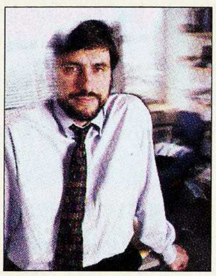

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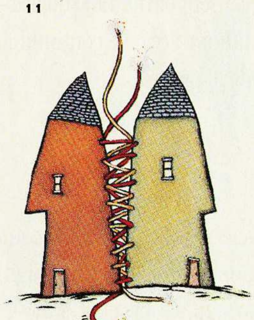

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Marking Time:
PHOTO CONTEST WINNERS

Recognizing the central role of time in science and technology, we challenged entrants in our annual event to portray the concept. Our winners produced strikingly different images.

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First Line

Message from The Comet

Phenomena like the comet Hale-Bopp can reinspire us to communicate with and enlighten one another.

On a windy, bitterly cold night in March, some 2,000 people crowded the Harvard Smithsonian Center for Astrophysics in Cambridge, Mass., to check out the comet Hale-Bopp from a telescope. Only after hours of standing in lines did some of us learn that the show was equally good through binoculars. Still, the mutual interest created something of a party atmosphere; we enjoyed one another while we waited.

Another evening, after disembarking from a commuter bus, I startled upon glimpsing the comet—which caused a woman walking past to stop, look up, and begin chatting with me about its rare visit as we trudged along to our homes. And a third night, when my family and I took a quick trip to witness the celestial object in the solitary darkness of the nearby countryside, another family seemed to materialize out of nowhere. With our kids sleeping in the cars, we parents stood in a field surrounded by spring peepers and just looked up, sharing our sense of awe. Hale-Bopp, shining so strongly after a 4,200-year hiatus, provided a common ground, so to speak, for people to breach their usual boundaries.

Most often *Technology Review* focuses on the implications of technology, the application of science, an emphasis with which I am delighted. No matter whether science rings one's chimes or not, I tell people unfamiliar with the publication that our magazine is an important read because of the omnipresent role of technology in our lives. And unless we consider its ramifications we have no hope of controlling them. I am a practical person, happy to be grounded in the topics *Technology Review* delves into repeatedly. Still, once in a while a natural event such as Hale-Bopp stirs up in me—and obviously in huge numbers of others as well—a very different set of emotions.

At *Technology Review* we refer to wonderful stories about pure science as "brighteners," and we enjoy presenting them. Extending the term's use a bit, I'd like to suggest that all of us remember the importance of paying homage to brighteners of *nature*: the booming thunderstorm, the sparkling meteor shower, the unexpectedly heavy snowfall, even the leafing out of a tree in spring or the curling of a woolly-bear caterpillar on a path.

How do we respect such events? First, we need to remember to stop long enough to attend to them. Kids do so all the time—sometimes to parents' exasperation—but we adults are often too busy churning through the details of our day-to-day responsibilities. (The growing amount of information we must process doesn't help—see "Data Smog: Surviving the Info Glut" by David Shenk in *Technology Review*'s May/June 1997 issue.)

Stopping provides significant benefits. At one level, notable natural occurrences can help us center our lives; Hale-Bopp led me to consider the vastness of time and in turn renewed my perspective on my usual activities. As many of us know from experience, striking natural events can also lead us into rewarding paths of inquiry: scientific, aesthetic, or some measure of both. And nature's brighteners can help us to remember our shared connections and to communicate a little more with one another.

The possibilities for investigation and communication are even broader, I believe. Perhaps we—and here I particularly mean *Technology Review* readers, who generally have backgrounds in science and engineering—can best pay tribute to natural phenomena by helping others explore and understand them. The local school system is one obvious outlet: either directly or by working with their teachers, we can help kids to talk about clouds and eclipses and life in ponds and to start down their own paths of scientific and aesthetic inquiry. Alternatives to schools include volunteering at museums, after-school programs, nature centers, or camps—perhaps helping such institutions to develop programs or learn the latest scientific thinking in a particular field. Or we can query editors of publications intended for popular audiences about writing articles—crisply, cleanly, and with a sense of storytelling and what's new—about topics that stir us and might similarly affect readers. If we're really feeling feisty, we can even try to interest politicians in science—knowledge that could have subtle and positive effects on laws and policies.

Leaders in the scientific community can exert a particularly salutary, and multiplier, effect. For example, Leroy Hood, the founder of the Department of Molecular Biotechnology at the University of Washington and inventor of the machine used for sequencing genetic information, is encouraging researchers in his large laboratory to spend 5 to 10 percent of their working hours teaching primary- and secondary-grade teachers.

Alan Hale—whose name, because of his role as one of its discoverers, graces the comet that recently visited us—favors science education himself. The founder and director of an organization concerned with providing the public with research opportunities in astronomy and space science, he has decried, in an interview with the *New York Times*, a general lack of scientific understanding, connecting the phenomenon with what he sees as too little support for science.

We should not cower under the mantle of being too busy to undertake extracurricular activities involving science and aesthetics. Almost everyone has plenty going on, but how else are we to make a difference in the period we have on earth? We can thank Hale-Bopp for reminding us how little time we have to act as well as wish upon a star. ■

—Laura van Dam

Laura van Dam is a senior editor at Technology Review.

Letters

THE VALUE OF A NATIONAL IGNITION FACILITY

"The National Ignition Facility: Buyer Beware" (*TR February/March 1997*) by Tom Zamora Collina is based principally on the incorrect assumption that warhead secondaries are not important, and that the weapons-stewardship science at the National Ignition Facility (NIF) would relate only to secondaries. There are uncertainties in secondary performance and the science-based stockpile stewardship approach must understand and predict rather than react to potential problems. But the NIF isn't just for secondaries.

The NIF is also designed to provide a window into the physics regimes of high temperature, density, and pressure that occur during nuclear-weapon detonation. These regimes occur in other environments such as astrophysics, but, in controlled laboratory conditions, only the NIF will be able to closely approximate the actual conditions that occur in nuclear weapons. The NIF's laser light can be used directly or converted to a bath of x-rays as hot as the interior of stars. The interaction of intense laser light or high-temperature x-rays with matter results in shocks, pressures, and material transitions that are important in both primary and secondary stages of a weapon. The evolution of features such as layers, cracks, bubbles, or bumps in response to such intense radiation is complex and can be studied at NIF on time scales and in dimensions directly applicable to maintaining a reliable weapons stockpile.

The NIF is needed to assess the nuclear detonation consequences of aging or any material change in weapons. The fact that information gleaned also has applications for basic research on materials, astrophysics, and fusion energy can only be viewed as a strong additional reason for supporting the NIF.

DAVID H. CRANDALL
Director
Office of Inertial Fusion and the NIF
Department of Energy
Washington, D.C.

Collina buttressed some of his skepticism about the NIF with anonymous opinions. For example, while he notes that Timothy Coffey, director of research at the Naval Research Laboratory, suggested delaying NIF in May 1994, Collina neglects to add that the 12 other members of the 1994 NIF review panel strongly recommended going ahead.

Collina says: "Prominent physicists recently wrote to Representative Ron Dellums (D-Calif.), the ranking Democrat on the House National Security Committee, urging his support for the project on the grounds that it would be 'important to fusion energy and basic science.'" Just who are these "prominent physicists" and what did they say about NIF and its role in the stockpile stewardship program?

The authors were: Hans Bethe, a Nobel laureate at Cornell University who was the head of the theoretical division of the Manhattan Project and a delegate to the first International Test Ban Conference in 1958; Henry Kendall, a Nobel laureate at MIT who is the founder and chair of the Union of Concerned Scientists; and Herbert York, the first director of Lawrence Livermore National Laboratory, the lead negotiator for the Comprehensive Test Ban Treaty from 1979 to 1981, the founder of the Institute on Global Conflict and Cooperation, and a chancellor of the

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University of California at San Diego.

The letter that Collina refers to states: "The decision about whether such a changed weapon will be safe and reliable ultimately depends upon the judgment of the weapons scientists—it is not an engineering judgment. In turn, the judgment of the scientists depends upon the availability of sound scientific understanding and calculation verified by thorough experimentation. . . . In a regime without nuclear tests, the U.S. has no current method of examining fusion ignition and the other high temperature and high density processes at conditions near those in an exploding weapon. The National Ignition Facility will play an important role in providing the needed information." Only toward the letter's conclusion do the authors note that NIF's "scientific investigation will also be important to fusion energy and basic science."

To make the best decisions about stockpile stewardship, our citizens and their elected representatives need as much information as possible, and the program must be debated fully and fairly.

VICTOR H. REIS
Assistant Secretary for Defense Programs
Department of Energy
Washington, D.C.

Collina supports taking minimal action with the nuclear stockpile until problems are obvious. Much of his article calls into question the impact of stockpile aging. As one of several individuals responsible for annually certifying the safety and reliability of the stockpile, I feel such a wait-and-see-approach would be irresponsible. As our recent report "Stockpile Surveillance: Past and Future" shows, the best projections indicate an average of one or two actionable findings per year in nuclear components. Without the tools to assess such changes as they occur, there is a much greater probability that I would have to recommend a nuclear test.

The author claims that the cost of the NIF would be $4.5 billion over a 30-year period. The actual cost of constructing the NIF is slightly under $1.2 billion, with all remaining costs associated with operating the facility. Nothing else in government, at your local supermarket, or anywhere else is calculated in the author's extended fashion—doing so would be the equivalent of adding insurance, gas, taxes, maintenance, and salaries of the driver and passengers to the sticker price of a car.

After spending the first three-quarters of the article questioning the stewardship program and the NIF, the author argues that they would significantly enhance nuclear proliferation by helping build nuclear expertise among scientists from other countries. The NIF has been designed for the stewardsip of the precision-designed stockpile of the United States, but is of little use to countries attempting to produce crude nuclear weapons. The Department of Energy conducted a multiagency review of the proliferation issues associated with the NIF and concluded that the facility posed an acceptable minimal risk.

C. BRUCE TARTER
Director
Lawrence Livermore National Laboratory
Livermore, Calif.

Collina's main grievance with stockpile stewardship appears to be the amount of money the government plans to spend on the NIF. What is lost in his diatribe is the corollary benefits to our national technical community of taking on challenges such as those presented by the NIF: igniting fusion reactions in the laboratory, studying the physics of stellar interiors, and greatly extending the capabilities of our nation in areas such as lasers, precision optics, high-speed instrumentation, and micromanufacturing.

STEPHEN O. DEAN
Gaithersburg, Md.

COOL IDEAS

Since 1992, American Forests, the nation's oldest conservation organization, has been demonstrating and researching the cool-communities principles discussed by Arthur H. Rosenfeld, Joseph J. Romm, Hashem Akbari, and Alan C. Lloyd in "Paint the Town White—and Green" (*TR February/*

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March 1997). By monitoring temperatures and vegetation amounts in the Atlanta area in 1972, 1983, 1986, and 1993, American Forests has documented the positive effects of trees on summer temperatures, energy conservation, and air quality over a 20-year period. It is dramatically obvious that as land cover increases, temperatures decline. We have found that along with reducing the temperature, trees are also saving the city about $50 million a year in stormwater-management costs.

Clearly the most significant finding of our study was that cities could save a lot of money and create better environments for their residents if they incorporated existing natural landscapes or provided more space for trees. Since land-use planning decisions are made locally, we converted the techniques we used to map and measure the Atlanta landscape to desktop-computer software so that communities can use them to explore various planning and development options.

GARY MOLL
American Forests
Washington, D.C.

Los Angeles smog does not result simply from industry dumping waste into the air but arises from millions of seemingly innocuous actions by individuals, businesses, and industry each day. Spurred by the summer heat and sunlight, the chemicals involved react with one another, resulting in smog.

Initial modeling at the South Coast Air Quality Management District indicates that a further 5° F rise in temperatures in the region would induce as much smog as dumping another 200 tons of common pollutants into the air each summer day. The cost of addressing this smog increase with more pollution controls could rise into the billions annually. The region's air-clean-up plan thus calls for investigating the use of lighter-colored materials in Los Angeles to reduce temperatures.

With such changes, Los Angeles will hopefully be able to cut its temperatures to near-natural levels, thereby reducing air-conditioning costs, making life more comfortable, and decreasing smog. But then residents will have to face the effects of global warming.

JAMES M. LENTS
Executive Officer
South Coast Air Quality Management District
Diamond Bar, Calif.

Commercial and industrial buildings often have flat roofs, which appear sterile and uninviting, often black and ugly, from the air. Why not cultivate mosses, lichens, and other similar plants? They would require little attention, and, once established, would not require large amounts of soil, which could increase the rooftop weight and pose a hazard. The hardiness of such plants is proven by their survival in the tundra above the Arctic Circle. Not only would such gardens beautify our cities from the air, but they would help reduce temperatures and pollutants and generate oxygen.

Through their beautiful moss gardens, the Japanese have converted the use of these plants into an art form. Since gardeners have traditionally conspired against mosses and lichens, the greatest barrier may be the negative mind-set toward them.

ANTONI TABAK
Waterford, Conn.

CHEMICAL CLARIFICATION

In "A Researcher's Conviction" (*TR February/March 1997*), Seth Shulman repeatedly refers to ammonium. In my 40 years of teaching high-school chemistry, I always distinguished carefully between ammonia, the NH_3 molecule, and ammonium, the NH_4^+ ion. Is the author referring to the individual compound or to some set of ammonium salts?

HARRY C. STUBBS
Milton, Mass.

The author replies:
I regret the lack of clarity. The patent refers to ammonium ions.

Continued on page 68

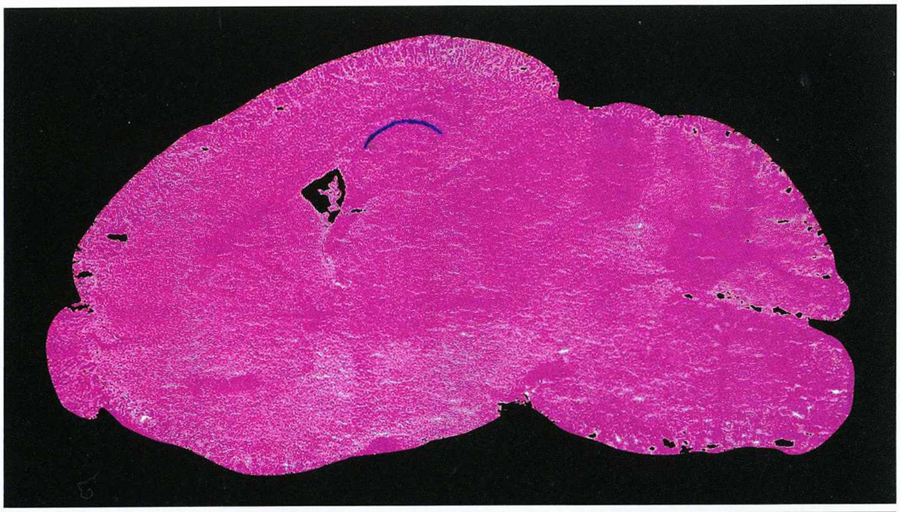
MIT Reporter

A Mightier Mouse

One of molecular biology's mightiest tools has been the knockout mouse. Although its name conjures up images of a cartoon animal that boasts, "Here I come to save the day" before duking it out with evil characters, this mouse is no fantasy. The knockout mouse has served as a model for human diseases and shed light on the workings of the brain. Now a new generation of knockout mice developed at MIT packs an even more powerful punch.

Knockout mice are laboratory strains engineered to lack a specific gene. By studying what happens when that gene is missing, researchers gain clues to its function. Until now the clues were fuzzy, says Susumu Tonegawa, director of MIT's Center for Learning and Memory and a Nobel laureate. Researchers could make a mouse lacking a key gene, but it would be missing throughout the mouse's body and its lifetime—from the earliest stages of embryonic development to death. Because a gene may have different functions in different parts of the body or at different times, investigators were hard pressed to draw conclusions from such "first-generation" knockout mice about exactly where and when the missing gene would have otherwise played a role.

To zero in on a gene's function, researchers need to knock it out only in certain locations or during a narrow window of time. That is what Tonegawa, Matthew Wilson—an assistant professor in the departments of Biology and Brain and Cognitive Sciences—and investigators at California Institute of Technology and Columbia University have done. They have created a new kind of knockout mouse in which a specific gene is deleted only in certain cells in the brain and only after neural circuitry has developed. The researchers have worked with a gene thought to affect the development of spatial memory, the mechanism by which we navigate familiar environments.



To determine whether a certain molecule affects spatial memory, researchers had to delete, in particular brain cells at a particular time, the gene that produces the substance. The molecule's absence resulted in the purple sliver near the top of this cross-sectioned mouse brain.

To create the new strain, the scientists attached an "on-off switch"—a stretch of DNA called a site-specific promoter because it controls activity in particular types of cells—to a molecular device that chops out genes. German researchers had used a similar approach to create a mouse strain lacking a gene in immune-system cells, but applying the technique to the brain was especially tricky, says Tonegawa. His group knew the gene chopper would work in actively dividing cells such as immune cells, but wasn't sure about brain cells, which stop dividing around the time of birth. The researchers also weren't sure that the on-off switch would restrict gene deletion as precisely as they wanted. Although subregions of the brain have quite different functions, the anatomy and organization of brain cells are virtually identical from one subregion to another. The team feared the promoter wouldn't be able to distinguish cells in a specific subregion.

Still, they tried the technique—and fortunately, says Tonegawa, "nature was kind." The system worked in the brain, and moreover, because the promoter happens to be inactive during development, it worked only after the neurons had fully formed. In a series of papers published late last year in the journal *Cell*, the scientists revealed that their "regional gene knockout technology" allowed them to determine which molecule is responsible for strengthening the neural connections that lead to spatial memory, and where that molecule exerts its effect. Stopping the gene from producing the particular molecule after neural development resulted in mice that, unlike normal mice, could not learn how to get out of a maze after being placed in it day after day. To confirm that the brains of the knockout mice were not undergoing the synaptic strengthening necessary to form mental maps of the maze, the researchers implanted tiny electrodes in the animals' brains and recorded activity from the neurons where the gene had been knocked out. By contrast, "first-generation" knockout mice previously devel-

PHOTO: JOE Z. TSIEN

oped to study spatial memory had died within a day or two, before researchers could study them. Apparently the gene was critical to survival early on.

The *Cell* papers created a stir among neuroscientists, who immediately saw ways to use regional and time-specific gene knockouts to explore other problems, including neurological disorders. Parkinson's disease, for example, results from the death of cells in a part of the brain called the substantia nigra. These cells normally release the neurotransmitter dopamine, so researchers have assumed that the disease results from the lack of dopamine, explains Zach Hall, director of the National Institute for Neurological Disorders and Stroke. Giving Parkinson's patients L-dopa, a dopamine precursor, lessens their symptoms, but only partly and temporarily. Maybe, says Hall, that's because substantia nigra cells supply not just dopamine but some other essential but unidentified product. Comparing the effect of knocking out just the genes that make dopamine at a particular time with removing the substantia nigra cells altogether could help pinpoint whether one or more other products play a role, he explains.

Applying the Technique Elsewhere

One neuroscientist eager to apply the new technique is Michael Stryker of the University of California, San Francisco. Stryker wants to understand the molecular mechanisms that underlie development of the visual cortex—the part of the brain that receives and processes input from the eyes. Work in his lab and others has shown that connections among neurons in the visual cortex form rather imprecisely at first. During normal development, the connections reorganize into the specific pattern necessary for normal vision—a process referred to as visual cortical plasticity. If that doesn't happen, the result can be diminished vision, often to the point of blindness.

Stryker, Alcino Silva, a senior staff investigator at Cold Spring Harbor Laboratory in New York, and their colleagues have previously experimented with first-generation knockout mice in an attempt to pinpoint what happens at the molecular level when connections in the visual cortex reorganize. But the results have been inconclusive. Stryker hopes that refining his experiments using regional and temporal gene knockout mice could better test his group's theory that connections in the visual cortex do not reorganize properly unless a particular molecule is present at a specific time in development.

Applying the new knockout technology to other parts of the brain such as the visual cortex will depend on the discovery of additional DNA sequences that turn genes on or off in particular regions. Toward this end, investigators can create many strains of transgenic mice with the same on-off switch. By chance, in each strain the switch tends to incorporate into a different DNA site. The intrinsic property of the switch and the DNA site where it integrates, in turn, dictate the part of the brain where the switch is active. The researchers are then picking out for further research those strains in which the switches are working in very specific regions of the brain.

The Tonegawa team is also trying to more precisely control the timing of knocking out genes. One way of doing this is by injecting a compound that triggers gene deletion. The experimenter can control the timing of the deletion by injecting the compound at a specific stage of development.

According to Stryker, this kind of work may eventually help researchers resolve a question of fundamental interest to neuroscientists: discovering "whether the mechanisms responsible for learning and memory are really just the same ones that are used in develop-

ment." Scientists know much more about the molecular mechanisms that underlie general development than they do about the mechanisms responsible for learning and memory. If similar processes are involved, many of the mysteries of the brain will be made clear rapidly. Moreover, says Wilson, research that identifies particular molecules at work in memory could eventually lead to techniques for reducing memory loss or even for improving normal memory.

—NANCY ROSS-FLANIGAN

SPENDING MORE AND ENJOYING IT LESS?

In a comedy sketch from the early '60s, a bereaved Mike Nichols approaches funeral director Elaine May and asks for the "$65 funeral." Items he thought would be included—the casket, the hearse, the driver, the burial—all turn out to be extra. Nichols ends up much the poorer, but only after enduring a torturous series of purchasing decisions. To Drazen Prelec, scenarios like this one illustrate a much neglected fact of economic life: while it always hurts to pay, some payment schemes make the suffering worse than it needs to be.

The guilt or anxiety we feel over parting with our shekels is a double-edged sword. On the plus side, the pain can keep us from overspending. But to our detriment, it takes some of the pleasure out of consuming. "There's a kind of 'moral tax' that we incur when we pay for something," says Prelec, an associate professor of management science at the MIT Sloan School of Management. "When you purchase any good, your enjoyment is reduced by the psychological cost of paying for it." This may strike some as blindingly obvious, but Prelec contends the moral tax has yet to find its way into any economic model. More important, he says, consumers and marketers alike would benefit if they explicitly sought pricing and payment systems that "let people enjoy things without thinking about paying."

Drazen Prelec of the MIT Sloan School of Management says producers should devote more attention to consumers' purchasing psychology; buyers generally prefer to pay in advance or through fixed fee for goods and services.

Prepayment, for example. In studies Prelec has performed with George Loewenstein, a professor of social and decision sciences at Carnegie Mellon University, consumers have made it clear that they hate the feeling of being in debt. "For some types of expenditures," says Prelec, "people claim they would prefer to prepay, even when there's no financial advantage." Vacations are such an expenditure. In one survey, consumers were asked to imagine they were planning a week in the Caribbean, at a cost of $1,200. Given the choice of making six monthly payments of $200 dollars either in advance or after their return, almost two-thirds of the respondents said they would rather prepay, even though they would incur a penalty in lost interest.

Similarly, once they're abroad, people seem to find it easier to spend in foreign currency. "It's almost like play money—it's prepaid in the psychological sense," Prelec says. He adds that Club Med is on to this psychology: guests buy beads to use instead of cash.

But the desire to prepay does not extend to all items. Most respondents to Prelec and Loewenstein's surveys said they would prefer to buy heavy appliances on credit. Why the difference? "Our explanation is that if you buy a washer and dryer on an installment plan, you don't feel as if you're in debt because you are paying for service that you continue to receive. Whereas when you come back from a vacation, it's history. You are in debt."

Another system that can take the sting out of paying is the flat rate—a fixed fee for unlimited service. It's well known that many people choose a flat rate for their local telephone service even though they would save money by selecting a plan based on actual use. But Prelec and Loewenstein's research suggests that the "flat-rate bias" may be a common consumer preference. Picture this: Two people use the same health club 10 times a month. One pays a $100 monthly fee, the other pays $10 per visit. Now, who enjoys the health club more?

Most survey respondents chose the

PHOTO: MARK OSTOW

person who pays once a month. "When you buy at a flat rate," says Prelec, "that's a form of prepayment—you know what the monthly bill is, you can deduct it from your budget, and then you can enjoy the service as if it were free."

Prix Fixe Preferred

In general, the fewer payment decisions a consumer has to make, the better. So when people are shopping for complex goods or services—items consisting of a basic unit plus add-ons—a product that is sold with everything included for a fixed price may enjoy an advantage over one requiring consumers to weigh the cost of each option. Examples of the latter abound. (Think funeral home or car dealer.) But Prelec also points to some products that have found success through all-inclusive pricing. The Wave, a popular high-end ($349) radio from Bose, for example, is sold through mail order and comes in only one model. The consumer avoids the typical audio-store experience of deliberating over competing brands and piecing together differently priced components. "The Wave radio is a self-contained unit with a single price," Prelec says. "You don't really know what each feature costs, so the moral tax is lower."

Software packages that promise free upgrades fit this category well. Of course, the cost of the upgrades is factored into the price of the first version. "Still," says Prelec, "that's a more attractive package than one where customers know they'll have to make a lot of subsequent decisions about incremental costs."

But just as there are legitimate methods for lowering the moral tax on a purchase, there are also insidious ones. In surveying the pitfalls of consumerism, Prelec has one word for you: plastic. "If paying for something is a bitter pill, then credit cards provide a little sugar coating," he says. They lessen the moral tax by giving the purchaser discretion over when and how much to pay. But in so doing, Prelec says, the cards "obscure the connection between debt and consumption. Mentally you feel as if your possessions have been paid for in full; you don't have any sort of accounting system that says this fancy vase is only two-thirds paid for. Now suddenly there are all these credit card bills. What are they for?"

Perhaps not surprisingly, consumers surveyed by Prelec and Loewenstein rated credit card payments the most distasteful kind of expenditure, even ahead of parking tickets and dental bills.

Prelec is optimistic that technology will come to consumers' rescue. "Smart cards"—now being developed as a potential substitute for cash—will contain chips that might help people track their expenditures better. And various prepaid cards (similar to some new phone cards) may ease anxieties about overspending. But in the meantime, Prelec says, the burden of lowering the moral tax may fall on producers: "We're trying to tell them, 'Look, people have some fundamental concerns about prices. Beyond just getting the number right, you have to create pricing systems—such as flat rates—that take into account the moral tax embedded in our psychology.' "

—DAVID BRITTAN

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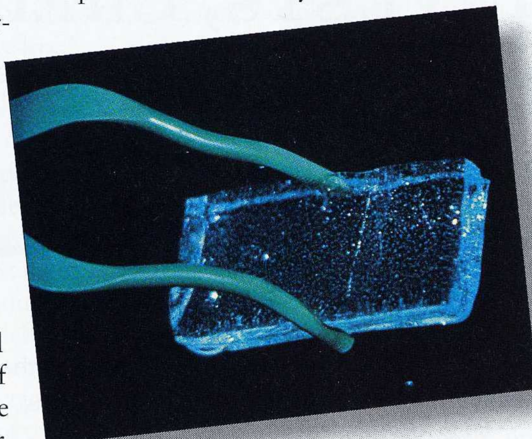
World History on Ice

From the outside, the storage shed on the University of New Hampshire (UNH) campus in Durham looks inconspicuous enough—a standard white 48-by-12-foot box. It doesn't look too remarkable from the inside, either, housing a few electric jigsaws and racks holding thousands of cylindrical canisters filled with ice. This is not your average ice locker, however. It contains all the pieces of a two-mile strip of ice drilled from a massive ice sheet in Greenland. Moreover, this ice holds vital data about the earth's climate over the past 250,000 years and offers the most detailed record yet of the last 110,000 years of our planet's history.

"In some ways, the ice sheets tell us more about what the environment was like in northern latitudes 100,000 years ago than we can learn about the 1700s and 1800s from human records," says Paul Mayewski, director of glacial research at UNH and chief scientist for the Greenland Ice Sheet Project Two (GISP2). "Those written records consist mainly of temperature readings, but we can use the ice to analyze 45 different variables."

Mayewski views the ice sheets as a "time machine" that not only tells us about the earth's history, including the effects of hundreds of volcanic eruptions, but also about human history. This frozen repository is providing a bounty of information to both earth scientists and archaeologists.

How can they extract so much information from ordinary chunks of ice? The Greenland ice sheets are composed of snow that falls to earth carrying compounds from the air, including chemicals, metals, dust, even radioactive fallout. The snow piles up layer by layer, year after year, trapping these substances. Pressure from the accumulating snow eventually creates ice, and bubbles that form in the ice seal off small samples of the atmosphere. In laboratories at UNH and elsewhere, scientists can precisely identify the yearly layers in the ice—like the rings in a tree trunk—to determine the composition of the atmosphere at that time.

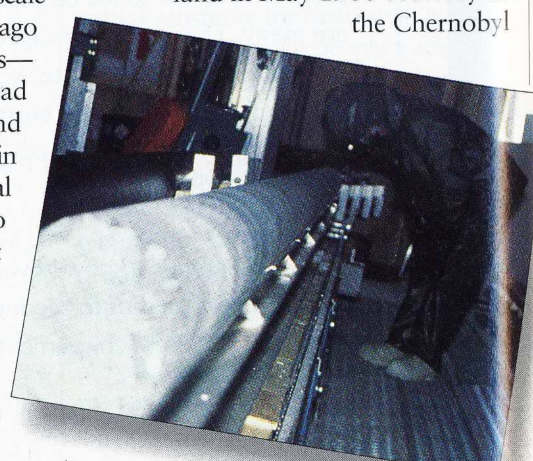


Greenland's frozen archives contain remarkable remnants of industrial enterprise over the ages. For instance, the record shows that the earliest large-scale pollution started about 2,500 years ago and continued for the next 800 years—the result of mining and smelting lead and silver during the Greek and Roman eras. In fact, lead pollution in that period rose to four times natural background levels, according to Claude Boutron, a French scientist whose team studied ice chunks from a parallel sampling effort, the European Greenland Ice-Core Project.

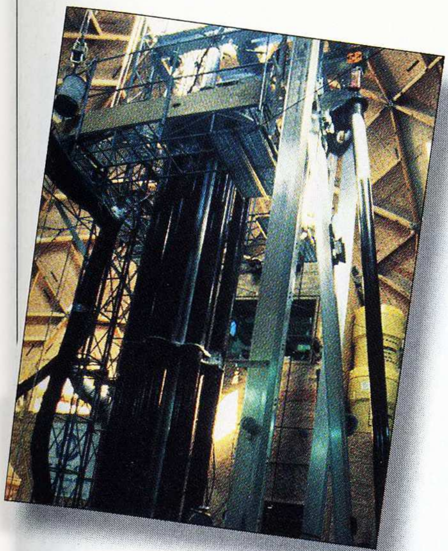
Other findings indicate that the decline of the Roman Empire was followed by a steady drop in lead pollution: lead concentrations in the ice cores fell during the Middle Ages and did not surpass the Roman levels until the start of the Industrial Revolution. An even sharper rise occurred in the twentieth century when lead concentrations rose to some 200 times natural (pre-Greek and Roman) levels, presumably owing largely to the introduction of lead additives to gasoline.

Other chemicals have also shown a dramatic upsurge. According to the ice core data, atmospheric concentrations of carbon dioxide climbed almost 30 percent, methane concentrations more than doubled, and concentrations of sulfate (a byproduct of coal combustion) have roughly tripled since the onset of the Industrial Revolution.

New pollutants began showing up in Greenland in the late-1950s—radioactive strontium-90 and cesium-137, fallout primarily from U.S., Soviet, and British nuclear testing programs. "This fallout reached a peak in 1963 and then dropped off with the signing of the atmospheric Test Ban Treaty later that year," says Jack Dibb, a UNH scientist in the Glacier Research Group. "We still see little bumps in the 1970s and '80s from tests by the Chinese, French, and perhaps some others we don't know about." More radioactive debris in the form of cesium-134 and 137 drifted to Greenland in May 1986 courtesy of the Chernobyl nuclear accident in the Ukraine. This radioactive cloud deposited isotopes in Antarctic ice, suggesting that the entire planet was con-



PHOTOS: M.C. MORRISON; M.S. TWICKLER



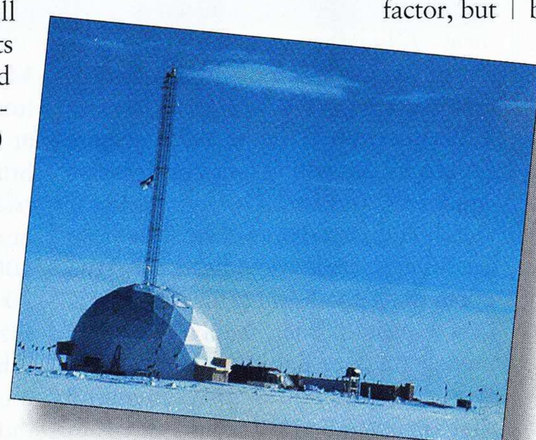
This tiny ice chip (far left) was sliced from pieces of a two-mile long cylindrical core (below left) drilled from a massive ice sheet in Greenland (above, below right). By analyzing the air bubbles trapped in the ice, researchers are piecing together a surprisingly detailed record of the world's air quality spanning some 250,000 years.

taminated by the core meltdown.

But the story the ice tells is not all bad. Concentrations of key pollutants (including lead) reaching Greenland have actually declined since the passage of the U.S. Clean Air Act in 1970 and the subsequent clamp-down on emissions. Still, over the 100,000-plus years these ice cores span, levels of carbon dioxide and methane, both greenhouse gases, have never been higher than they are today, says Martin Wahlen, a physicist at the Scripps Institute of Oceanography, and the magnitude of this human-induced change is truly remarkable. With respect to carbon dioxide and methane concentrations, he says, "humanity has brought about a change of roughly the same magnitude as that which naturally occurs between glacial and interglacial periods." Whereas this natural shift took place over the course of tens of thousands of years, however, the human-induced change occurred within only the past few centuries.

One of the biggest surprises to emerge from the GISP2 project is the discovery of rapid climate shifts that occur within a time frame of decades or less. "We've shown, on at least eight separate occasions, that climate change has occurred abruptly as civilizations were developing in the last several thousand years," Mayewski says. These changes can put people living in extreme environments—either very cold or arid—at risk. "If you live in a marginal area like that, a slight change in temperature or moisture can put you out of business."

For example, Mayewski and Yale archaeologist Harvey Weiss have found a surprising correlation between a climatic "event" in 2,200 B.C., which resulted in extreme drought from Europe to India, and the collapse of the Mesopotamian Empire, which was based near a desert region in what is now Iraq. "That doesn't mean climate change was the only factor, but it probably played some role," Mayewski says.



Mayewski teamed up with archaeologist Tom McGovern of Hunter College and others to investigate a similar long-standing mystery regarding the disappearance of Norse settlers in Western Greenland beginning in the mid-1300s. "The core records indicate a really cold winter around the year 1350 and a series of progressively colder summers," McGovern says. "The worst news for these people would have been a series of cold summers, which would have reduced an already short growing season, and that's exactly what happened." The climate, he adds, had always been suspected of playing a role in wiping out the settlement, but "we needed the new ice core data, which has a resolution on the scale of individual years and seasons, to really pin it down."

McGovern next hopes to find out whether the widespread die-offs of mastodons, woolly mammoths, and other animals 10,000 years ago at the end of the Pleistocene era were due mainly to climate change or to human predation. "There's been a tremendous debate in archaeology for years, and the Greenland data can finally help us resolve it."

Mayewski expects that future studies will turn up many other associations between the climate events revealed in the ice sheets and major turning points in human history. The next step, he says, is to produce ice cores from other parts of the world—hence a deep-drilling program that began last year in Antarctica. The GISP2 collaborators are also beginning to compare the ice core data with corresponding climate records obtained from tree rings, lake sediments, and coral.

The key is not just to pool the data, McGovern says—"You really need to bring people together to form diverse teams," and collaborations of this sort between climatologists, archaeologists, paleontologists, and historians are "opening up a whole new area" with tremendous potential. In terms of exploiting the body of information locked deep in the world's ice sheets, Mayewski adds, "we've only begun to scratch the surface."—STEVE NADIS

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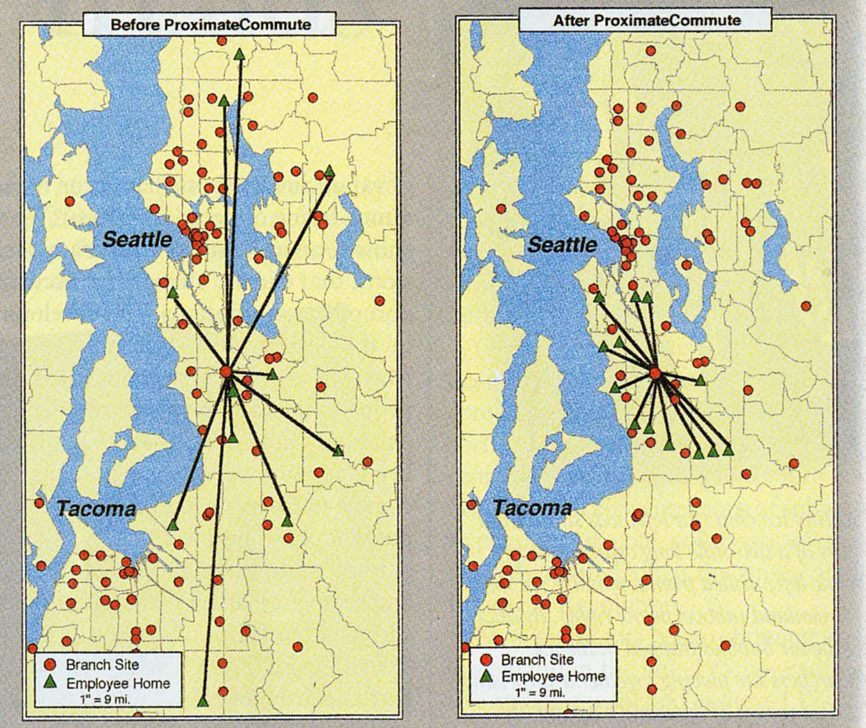


Employees of Key Bank's Riverton Heights branch cut their commuting distance by 60 percent after swapping jobs with employees who live closer to other branches—thanks to a program that assigned each employee participating in the project to the branch nearest his or her home.

Trading Places

Three years ago, before she became a pioneer on the transportation frontier, Justy Mayernik did what millions of other commuters do—and hated it. She spent two to three hours each weekday driving between her home southeast of Seattle and her job as a teller at a Key Bank 30 miles north—adding her straw to a staggering load of traffic congestion, air pollution, and costly demands on the transportation infrastructure. She and her husband once lived closer to her workplace, but had moved to one of the last spots in that booming region where they could still afford a house.

Meanwhile, unbeknownst to Mayernik, another teller, George Nelson, was driving nearly as far from his home north of Seattle to a Key Bank branch just 20 minutes from Mayernik's home. Justy and George might still be passing on the interstate, if an environmental consultant named Gene Mullins hadn't gotten trapped in a daily commuting nightmare after his office moved from Seattle, where he lived, to the suburbs. "I thought there ought to be a better way to match up where people live and where they work," Mullins recalls. While staring at his frazzled counterparts commuting in the opposite direction, he found himself musing that "it's too bad we can't just switch sites."

Such a switch might not work for a specialized professional like Mullins, who soon quit the long commute and started his own firm anyway. But he began to hear about people who worked in jobs that were likely to be interchangeable with others much closer to their homes. For example, he knew of a data-entry clerk who was driving 60 miles from Seattle to work in Olympia and a receptionist, two tellers, and a truck driver who were traveling nearly as far from Mount Vernon to Seattle.

Mullins had stumbled on a critical fact that transportation planners overlook: proximity is often the last thing companies consider in hiring and placing employees. Workers may seek jobs near their homes, but they take what they can get. "Once people are situated, they tend not to think about where they could be," says Laurie Turner, human resource manager at Key Bank. And even when they do think about it, they often find that their employers aren't set up to accommodate them.

To help employers and employees make more rational siting choices, Mullins devised a computer-based "proximate commuting" program and received funding from the state Transportation Department to conduct a trial of the scheme, with a review by the University of Washington's State Transportation Center. He says he approached Key Bank about being the guinea pig because it was promoting its environmental awareness.

Once Key Bank agreed to participate, Mullins conducted an initial study and found that only 17 percent of employees at 14 Key Bank branches worked at the branches nearest their homes. The rest resided, on average, closer to 10 other branches; some lived closer to more than 100. Mullins next met with workers at 30 branches and showed them how far they lived from their workplaces and other potential work sites, and how much their commuting cost them and the environment. "They'd be astonished at his maps," Turner recalls.

When Mullins finished his presentations, 17 percent of 500 employees volunteered to participate in the job-swapping scheme. Mullins's software, called Proximate Commute Mapper, mixed and matched their various locations and came up with mutually advantageous moves, which required the consent of both the workers and their managers. Justy Mayernik and George Nelson were the first to swap.

The results were dramatic. After two years, the average commute for all work-

MAPS: PROXIMATECOMMUTE

ers at the 30 bank branches had dropped by 17 percent; at one Tacoma branch, it fell by 69 percent. Participating workers cut their average round-trip commute by 65 percent, from 43 to 17 miles. Mullins estimates that each saved an average of $2,626 in commuting expenses and 216 hours in commuting time, and avoided emitting 5,940 pounds of carbon dioxide and 587 pounds of hydrocarbons per year. Proximate commuting also reduced stress and tardiness and boosted morale. "All the transfers we made have been successful," says Turner.

Extrapolating these results, Mullins figures that if 5 percent of all Seattle-area commuters were to make such swaps, they'd save 14 million hours and $170 million a year. That's not an unreasonable target, he argues, since 48 percent of Seattle-area workers and 39 percent of Washington state workers have multisite employers—and single-site firms, which sometimes share training programs, might also be able to join in proximate job swaps. Baseball teams trade employees, he notes, why shouldn't hardware stores?

After the Key Bank trial, University of Washington evaluator Cyrus Ulberg agreed, recommending that the state sponsor longer-term tests among different employers and offer incentives to pursue proximate commuting.

Meanwhile, Mullins has won rich praise and a shelf full of awards from local, state, and federal agencies, including a national prize from the Environmental Protection Agency. "It is a tremendous idea for companies like banks and grocery stores," says Paula Van Lare, coordinator of the EPA's Transportation Partners program. "In the transportation field, there are very few simple solutions, because transportation decisions are so deeply embedded in people's daily lives and lifestyles. It's nice to come across one like this, which can be implemented quickly."

Transit and carpooling, in contrast, demand sacrifices in time, convenience, and flexibility. Companies must be coerced into providing vanpools and inducing their workers to cease solo driving. Telecommuting, job-sharing, and four-day workweeks are only partial solutions; even telecommuters typically come to the office several times a week, and require changes in workplace culture and the way managers manage. And new rail and other mass transit chew up cityscapes and impose enormous capital costs.

So why isn't the world beating a path—as best it can through today's gridlock—to Mullins's door? Why has no other company adopted Mullins's scheme? "The idea ought to be able to sell itself, but it doesn't seem to," says Wayne Elson, a specialist in pollution from mobile sources at the EPA's Seattle regional office. Novelty may be one reason: transportation planners seek ways to move people over set distances, not to reduce those distances. The EPA's Van Lare suspects that businesses don't see the payoff from something like proximate commuting because "the rate of return is not explicit." And, she adds, "It's nobody's job to think about how people get to work." So nobody does.

That may change. Matthew McCandlis, transportation supervisor of the Seattle-based Starbucks coffee chain, hopes to offer proximate job-swapping to at least some of the company's 20,000 coffeehouse workers this autumn. Reducing turnover is a main motive. "We think we can keep them happy, add a lot to our retention rates, and reduce training costs," he says. Justy Mayernik, still happily working in her new location, would second the notion. "It's just nice," she says, "not having to get up at the crack of dawn and dread going to work every morning."

—*ERIC SCIGLIANO*

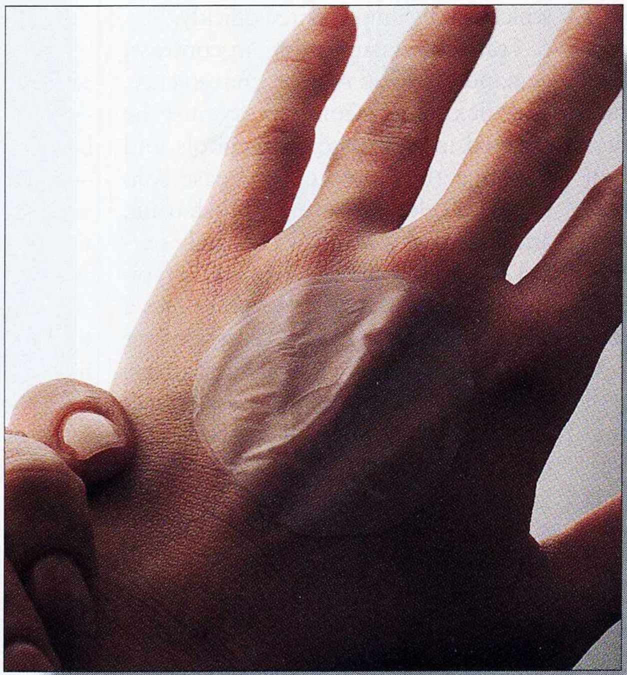
Brave New Skin

Nature knew what she was doing when she designed skin, the body's largest organ. As a covering for the body, nothing else comes close as a first level of defense against infection, trauma, and dehydration. The problem is that skin is always in short supply for the 4 million people plagued by chronic wounds and the more than 50,000 people hospitalized for burn treatment in the United States each year.

Traditional treatments for these painful and often life-threatening conditions include dressings that protect smaller wounds and passively allow the body to heal. Treatment for large or stubborn wounds may entail skin grafting. But a skin-graft operation requires hospitalization and creates another wound at the donor site. And after a great deal of pain, trouble, and expense the graft simply doesn't always survive.

Dissatisfied with these conventional treatments, researchers in the 1980s eagerly tried to isolate naturally occurring growth factors that promote healing. But the results with single growth factors have been generally disappointing because wound healing has turned out to be more complex than researchers originally thought, and figuring out which factors to daub on a wound, when, and at what dose remains a daunting task.

Scientists have therefore turned to cultured skin, hoping that it would not only provide a much needed covering but also be ready to use off the shelf without the need for donor matching. In fact, one novel type of cultured skin, called Apligraf Living Skin Equivalent, has shown great promise in that regard. According to its manufacturer, Organogenesis of Canton, Mass., when the living-skin tissue was used in clinical studies on patients with venous ulcers, which normally occur on the legs and feet as a result of abnormal blood drainage, wounds healed on average in 57 days. Comparable wounds treated with standard therapy using pressure dressings healed on average in 181 days. And 57 percent of patients who had battled their ulcers for more than a year saw their wounds close completely, compared with 17 percent of those receiving conventional treatment.



Living skin tissue, grown in the lab from two common skin cells, has proven effective in healing stubborn wounds without rejection by the immune system. As the patient's cells gradually replace the tissue, it takes on the appearance and color of the patient's own skin.

Other companies such as Advanced Tissue Sciences in La Jolla, Calif., are working on cultured-skin products, but the Organogenesis skin is unique because, unlike other products, it has two living layers—an outer epidermis and an underlying dermis. "Without both parts, you don't really have skin," says David Heimbach, director of the University of Washington Burn Center.

Epidermis, the thin, protective top layer, is nourished from the thicker, more sensitive layer of dermis below. As the dead, flat cells that compose the outermost part of the epidermis wear away, they're replaced with rapidly dividing cells from below called keratinocytes, which produce a tough protein and a unique fatty substance that makes skin waterproof. The dermis—composed primarily of fibroblast cells—contains the skin's blood vessels, lymph vessels, nerves, hair follicles, sweat glands, oil glands, and a network of the fibrous protein collagen, which gives skin flexibility and structural support.

The key to developing the new lab-grown skin is to cultivate only the dominant functional cells: keratinocytes and fibroblasts. While the immune system rejects other transplanted cells found in skin, for some unknown reason it accepts these two as benign.

The manufacturing process begins with skin that would normally be discarded—foreskins from circumcised infants. A bit of skin the size of a postage stamp can produce about four acres of skin equivalent. Once the tissue is broken down mechanically and enzymatically to the cellular level, highly selective growth conditions nourish only the keratinocytes and fibroblasts, thus purging the culture of unwanted cell types. Tech-

PHOTO: ORGANOGENESIS, INC.

nicians then mix the fibroblasts with a specially prepared collagen solution, which forms a gel that the cells reshape to a dense lattice. Keratinocytes laid upon this layer attach and, when exposed to the air, start to form the epidermis.

The resulting skin looks, feels, and behaves like normal human skin. When wounded, it can even heal itself. And it can be grown in any size or shape, though for medical convenience Organogenesis provides it in three-inch disks and four-by-eight-inch rectangles—sizes burn surgeons are accustomed to using. The cultured skin also adapts remarkably well to its new environment. Indeed, none of the patients in the clinical trial showed any signs of immunological rejection. And, perhaps most remarkably, the patient's own cells eventually replace the foreign tissue and the cells responsible for pigmentation return, along with normal skin color.

"The results have been dramatic," says Morton Altman, a research consultant with the California College of Podiatric Medicine in San Francisco who helped test the cultured skin. Patients reported almost instantaneous pain reduction, and healing was rapid, he says.

Despite such enthusiasm, two hurdles remain. Organogenesis has applied for FDA approval and has received expedited review status. But a nod from the FDA, while still necessary, is no longer sufficient for success, says Howard Jones, who heads regulatory affairs and licensing for Curative Technologies, which closely monitors the skin-dressing market in the course of running a nationwide network of wound-care centers. In the new era of managed care, manufacturers must make a case for the cost-effectiveness of new products.

But while a price has not yet been set for its cultured skin, Organogenesis estimates that it could be priced at more than $1,000 for a venous-ulcer treatment, for example, and still prove cheaper than standard therapy. And the developers are confident they can produce it for less. Although cell culture can be a painstaking process, large production lots should provide economies of scale.

Should the product clear these hurdles, it will become the first engineered living tissue to make it to market. And this brave new skin may be only the beginning. Scientists are also developing other tissue products such as blood vessels, heart valves, cartilage, and even whole organs. As with cultured skin, they are finding that their most important allies are the cells that already know how to make these complex tissues.

—*CAROLYN J. STRANGE*

Marking Time

OUR PHOTO CONTEST WINNERS

LET those in love wax long and ardently about the gossamer quality of their emotional state. No less tantalizing or challenging is the task of describing the passage of time. As with love, many ways exist. Scientists and engineers who study time or deal with the evanescent stuff in the course of experiments express its passage in terms of numbers, equations, and curves on graphs. Artists use other media: musicians delineate time through notes and spaces; visual artists must seek out objects or scenes that convey the concept.

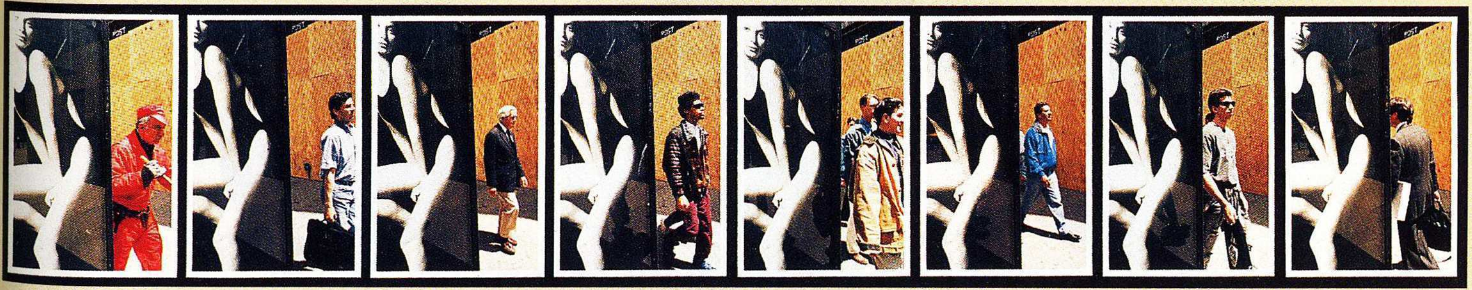
In this year's *Technology Review* photo contest we challenged entrants to depict events evolving over time or to portray creative methods of recording changes over time. We wanted to show how artists interpret a scientific notion. Contestants responded with a plethora of images: crumbling edifices, smokestacks juxtaposed against modern antennae, bodies healing from injuries, even a woman pulling up stockings. The winning photographs hint at the breadth of ideas.

The judges included Peter Vandermark, assistant professor of photojournalism at Boston University, and Felice Frankel and George Whitesides, who are, respectively, artist-in-residence at MIT and professor of chemistry at Harvard University and coauthors of *On the Surface of Things*, a collection of photographs and essays to be published in October by Chronicle Books. We thank all three for their thoughtful deliberations—and time.

1

The first-place image, "A Moment in Time" by David Freese of Philadelphia, suggests "a beginning and end, a past and future," remarked judge Vandermark. Freese evoked scientific imagery related to time—perhaps rocket trails or lines on a graph—through the use of two pieces of piano wire that he suspended in space against a black backdrop. Frankel found the photo "unbelievably spare and almost perfectly composed." Freese used a 4x5 camera and Kodak T-MAX 2100 film to produce the photo.

Todd Gieg of Boston wins second place for his image of the bedroom where he boarded at a private high school. The judges responded to the sense of timelessness in the image; the viewer has "no idea when this picture was taken," commented Vandermark. Producing the image required the passage of time: Gieg used a Hasselblad camera outfitted with a Polaroid back and 665 film he had first aged by exposing it to light-free air for at least a month, a technique that changes highlights and the colors of shadows. He hung the photograph on a wall for half a year or so, then coated the image area, which had undergone more chemical changes, to stop the aging process. The surrounding area sustained further chemical alterations for at least a year. Gieg finally removed the original coating and sealed the entire photograph with varnish.



Third prize goes to Marie Triller of Albany, N.Y., for her series depicting people walking past a Calvin Klein advertisement in New York's Times Square. The judges especially responded to Triller's colorful composition of the characters she had photographed during what she calls "a tiny fragment of time." Triller used a Nikon FA camera and Kodak 100 film.

WHAT WE Don't Know

Some critics claim that all the great questions in science have already been answered or are simply unanswerable. But a leading defender argues that reports of science's death have been greatly exaggerated.

THIS FALL will mark the thirtieth anniversary of an important milestone in my education. It was then, inspired by a great teacher, David R. Wones, that I declared Course XII, earth science, as my undergraduate major at MIT. To his students, Professor Wones seemed to possess an encyclopedic knowledge of rocks, minerals, geomorphology, and plate tectonics. He demanded much of us, with lengthy lab exercises and exhausting field trips in the New England rain. But his enthusiasm for scientific discovery—his passion to learn the things that we don't know but might someday find out—was infectious. He rekindled in me the deep curiosity that everyone feels as a child, and he focused that untutored, youthful instinct into an exacting experimental rigor. How shocking and sad, then, to read that I may be one of the last of a breed, for

BY ROBERT M. HAZEN

Illustrations by James Endicott

science, we are told, has entered its twilight, the victim of its own success. An eager pack of science watchers, led by science journalist John Horgan, author of *The End of Science: Facing the Limits of Knowledge in the Twilight of the Scientific Age* (Addison-Wesley, 1996) would have us believe that the end of science is at hand (*see "The Twilight of Science" by John Horgan, TR July 1996*). We are nearing the time, these observers contend, when we will have deduced all the great laws of nature and learned everything of significance about the natural world that can be learned. There are only so many things to find out, Horgan says, and each discovery brings us closer to closure. J. J. Thompson discovered the electron, so check that off the list. Evolution by natural selection, nuclear reactions, electromagnetic radiation, DNA—soon we'll know it all.

What rubbish! Such facile claims ignore the nature of the scientific process and the character of the questions it attempts to answer. Horgan is at least honest enough to warn unsuspecting readers that his college studies of literary criticism taught him to write analysis that is not "the final word" but rather "more clever, more interesting than the rest." Horgan is a clever writer, and he has managed to say something interesting, if exceptionally misleading.

But Horgan's smoke and mirrors is more than harmless literary legerdemain. By using stylish prose to cast doubt about the future vitality of science, he runs the risk of creating a self-fulfilling prophecy. Why should the public support basic research if nothing of interest is left to discover?

William Harvey, the seventeenth-century English physician who discovered the nature of blood's circulation, spoke for today's researchers when he said, "All that we know is still infinitely less than all that remains unknown." The key to understanding why science is an endless frontier lies not in cataloging what we know but rather in recognizing the vast amount of what remains unknown—the unanswered questions. These questions, which drive basic scientific research, fall logically into three broad categories of inquiry—questions about what exists, how it came to be, and how nature works. As the following summary of today's leading research demonstrates, those questions are inherently unlimited in scope, and the chain of discovery—and human curiosity that drives the quest for knowledge—shows not the slightest sign of ending.

What's Out There?

Questions about what exists mark the starting point of science. Scientific explorers of the past reveled in voyaging to exotic lands in pursuit of animal, plant, and mineral specimens. Chemists isolated element after element, physicians dissected diseased corpses, astronomers cataloged countless stars, and physicists scrutinized unusual phenomena associated with electricity and magnetism.

Even after centuries of labors, by most estimates we have identified only one or two percent of all living species on earth, have sampled only the thin outer skin of the planet, and have described only a few of the 80,000 proteins that our bodies produce. We know all 100 or so stable elements of the periodic table, but the number of possible combinations of these elements is for all intents and purposes infinite. Looking outward to space, we observe tens of billions of stars in each of tens of billions of galaxies—perhaps a trillion solar systems exist for every human. There is so much left to discover.

> Ninety-nine percent of the universe consists of strange dark matter unlike anything we now can comprehend.

Skeptics would have us believe that the hundreds of thousands of scientists around the world who devote their lives to exploring these domains are like high-tech postage-stamp collectors—filling in a few blanks rather than pursuing interesting research. These skeptics are wrong. The earth, our solar system, and the universe beyond holds wonders to captivate (and profit) the human race for millennia.

Moreover, if the task of describing the tangible universe weren't enough, it now appears that most of the mass of the universe—as much as 99 percent by some estimates—is missing, evidently consisting of strange matter unlike anything we now comprehend. Within the past two decades astronomers have discovered overwhelming evidence that the universe is littered with dark matter—seemingly invisible stuff that must be out there but can't be found even with our most powerful telescopes.

Almost all of the universe's matter that we know about is concentrated in galaxies, which exist on a scale almost beyond comprehension. Each galaxy holds tens to hundreds of billions of stars in a region that may exceed a 100,000 light years in diameter (a light year, the distance light travels in a year, is almost 6 trillion miles). Our own galaxy, the Milky Way, contains all the stars and constellations that are familiar to us in the night sky, but billions of other galaxies

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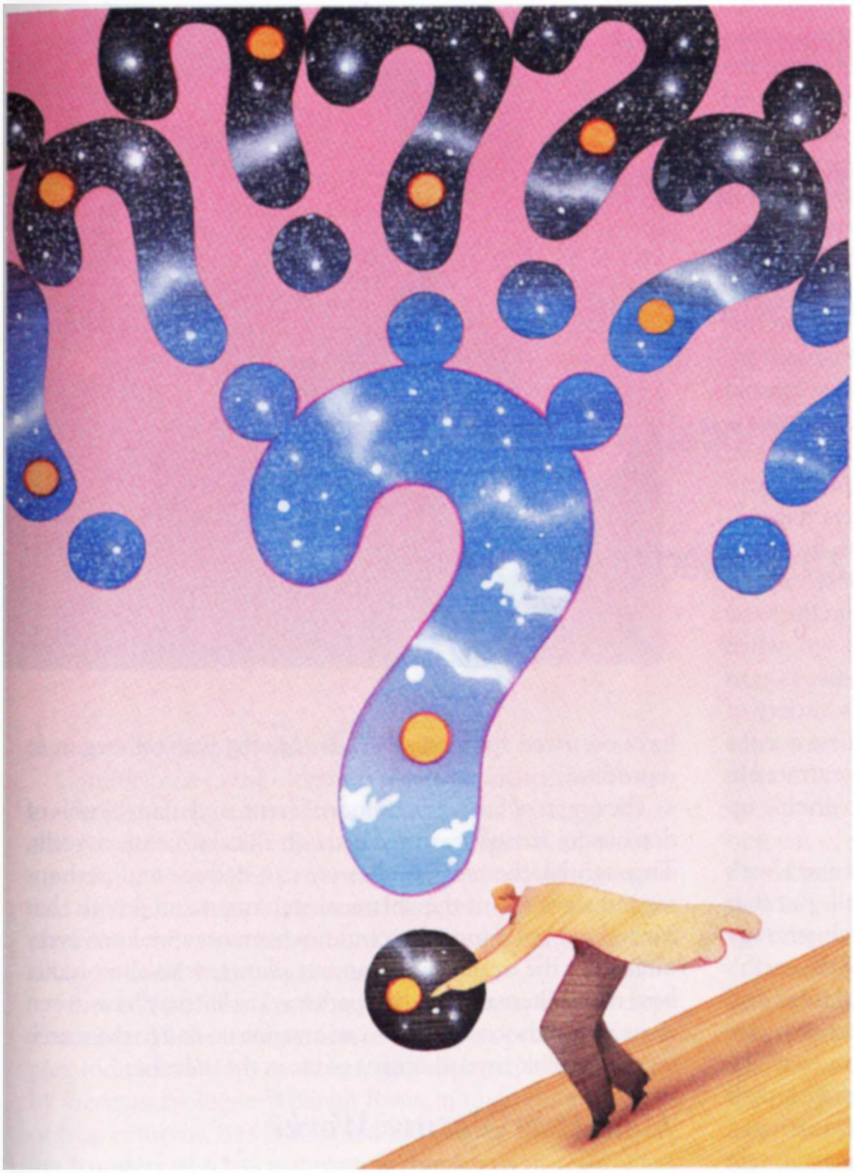
are also easily visible with the aid of telescopes.

For astronomers who want to study the nature and distribution of the universe's mass, galaxies are the logical place to start. These scientists rely on two complementary methods to estimate a galaxy's mass. The quick and easy way is to count the total number of visible stars (an effort simplified by image-processing computers), and then multiply that number times the average mass per star (a value painstakingly determined from observations and theory). This calculated value is known as the "visible mass" of a galaxy.



Alternatively, astronomers determine the "dynamical mass" of a galaxy by observing how stars move. Specifically, they measure the position and orbital speed of its stars or clouds of gas as they circle about the galactic center, the locus of immense gravitational forces. The more massive the galaxy, the faster its stars must travel in their galactic orbits to keep from falling in, closer to the center. Ultimately, if we have properly accounted for all of a galaxy's variables, the visible mass should exactly match the dynamical mass.

But in the 1970s astronomers discovered that outer portions of spiral galaxies rotate two to three times faster than they should, based on the gravity produced by stars we can see. The simple equation describing orbits has only three variables: orbital distance, orbital speed, and mass. Two of these variables, orbital distance and speed, can be measured by telescopic observations, so a galaxy's true mass can be calculated. The conclusion: estimates of mass based on visible stars are wrong; most of a galaxy's mass is not visible. It follows that most of the matter in the universe is dark and invisible.

Speculation about the nature of dark matter abounds. The first step is to eliminate what dark matter isn't: It can't be made of ordinary clumps of matter like snowballs or black holes, because we could detect its effects on light arriving from more distant sources. It can't be made of electrically charged particles like electrons or protons, because such particles emit telltale electromagnetic radiation. Indeed, the fact that we can't presently detect dark matter in the laboratory suggests that it must pass right through ordinary collections of atoms.

Faced with these daunting constraints, scientists have postulated a number of weird possibilities for the missing mass—exotic subatomic particles such as massive neutrinos or axions, mini black holes, or clusters of quarks called quark nuggets—but no one knows for sure. Around the world, teams of physicists are struggling to design more sensitive detectors to capture the subtle signals of dark matter. It may take many decades, but researchers are not likely to give up for lack of interest.

If all our present science is based on observations and measurements of a paltry 1 percent of reality's building blocks—everyday atomic matter—then how can physics be almost over? The search for dark matter, still in its barest infancy, is not a trivial academic pursuit. In fact, the nature and amount of missing mass is closely tied to the ultimate fate of the universe, namely whether the expanding universe's enormous gravity will eventually cause it to slow and finally collapse back into itself. The missing mass problem thus lies at the heart of our most fundamental attempts to understand the past, present, and future state of the cosmos.

Moreover, how astounding it is to think that the stuff of which we are made and the only matter we know may constitute only a tiny fraction of what exists. We are confronted

with so many questions: What is this strange stuff? How can we study it? What laws govern its behavior? And if we can confine and shape this matter to our will, what undreamed of technologies might follow?

How Did All This Come to Be?

Origin questions fascinate today's scientists, just as they have human thinkers since before recorded history. The origin of the universe remains perhaps the greatest cosmological question, with scientists, philosophers, and theologians all staking a claim to the answer. Locally in the cosmos, the origins of our galaxy and solar system are questions of mythic stature that invite broad speculation and foster intense debate. But of all the origin questions, the origin of life is certainly among the most profound. Fortunately, it is also highly amenable to exploration through experimental science, since it is a chemical process that might be duplicated in the laboratory.

Two complementary research strategies converge on origin of life questions. The quest to create life in the laboratory began in 1952 when University of Chicago professor Harold Urey and graduate student Stanley Miller devised glassware that sent electric sparks though a primordial atmosphere of methane, hydrogen, and ammonia circulating above warm water. Much to their surprise, in a matter of days the simple solution turned from colorless to pink to red to brown as a rich broth of organic molecules formed. These experiments, which in essence work forward in time from the basic carbon compounds that existed 4.5 billion years ago, when the earth first began to form, reveal that the primitive oceans must have become stocked rather quickly with a variety of relatively complex organic molecules. The earliest oceans and sediments may have grown increasingly concentrated in these organic molecules, for there was no life to gobble up the rich mix.

There is still a tremendous gap between Miller and Urey's sterile soup of organic molecules and a living cell. But that gap may be narrowed by an alternative research strategy that examines the chemical mechanisms of two of the earth's most primitive single-celled organisms: mycoplasma and cyanobacteria. The smallest of these, mycoplasma cells, are only about one ten-thousandth of an inch in diameter. The least complex life forms known, these cells depend on their environment to supply many kinds of organic nutrients, including amino acids and nucleic acids. Cyanobacteria, in contrast, are larger and more complex single cells, but they have the ability to survive and reproduce entirely from the most basic ingredients—carbon dioxide, nitrogen, and water, plus a few mineral nutrients.

The structural simplicity of mycoplasma and the chemical simplicity of cyanobacteria can illuminate different aspects of early life. For example, the cellular structures and metabolic pathways by which cells extract energy from sugar are common to all life forms, and must have been present in some fashion in the earliest cells. By paring down metabolism to its most basic chemical reactions, scientists hope to glimpse a plausible sequence of events that might

have occurred spontaneously, before the first cell began to reproduce.

The origin of life was a historical event, and many details of that history are still preserved in the chemical structures of cells. Through biochemical studies we can deduce and perhaps reproduce some of the chemical steps associated with that event. But even if someday centuries from now we learn every nuance of the origin of life on our planet, who can predict how many alternate chemical pathways to life may have arisen elsewhere in the cosmos? We can imagine no end to the search for the possible myriad origins of life in the universe.

How Does Nature Work?

The third, and arguably most open-ended, type of scientific question seeks to understand the processes by which nature works: how stars evolve, how rocks erode, how cancer develops, how atoms interact, how fungi reproduce—on and on, questions that arise by the millions. Descriptions of the dynamic evolution and interplay of natural systems help us not only understand the past and present but also predict the future of our physical surroundings. Perhaps of more immediate interest, knowledge of how nature works will help us address problems of fundamental importance to our well being. In fact, most of today's basic scientific research focuses on answering such questions, and the find-

The origin of life is a profound mystery, but one highly amenable to laboratory experiments.

ings are revealing bewildering complexity.

Consider one of the oldest mysteries of science: how a single fertilized egg transforms into a human being. As an embryo develops, cells must adopt exact spatial relations in a precise time-ordered pattern. As the first cell divides again and again, head, gut, legs, and heart assume their unique identities while new generations of cells play the specialized roles of blood, bone, and brain.

How is it possible for the genes in a solitary fertilized egg to contain all the information necessary to produce a complex individual? This question, first explored a century ago by German biologist Wilhelm Roux in microscopic studies of frog embryos, has blossomed into one of the most exciting frontiers of science, engaging thousands of researchers and showing no sign that a complete answer will ever be forthcoming.

Moreover, it's hard to imagine a scientific question that will have a more complex and lengthy answer. Documenting and describing the countless individual steps that yield a single fly—the rough bristles of its legs, the regimented facets of its eye, the exquisite tracery of its wings—will require thousands of thick volumes, each richly illustrated and dense in the jargon of genetics. For a human being, the volumes might number in the millions, and we are still a long way from knowing what to put in such books.

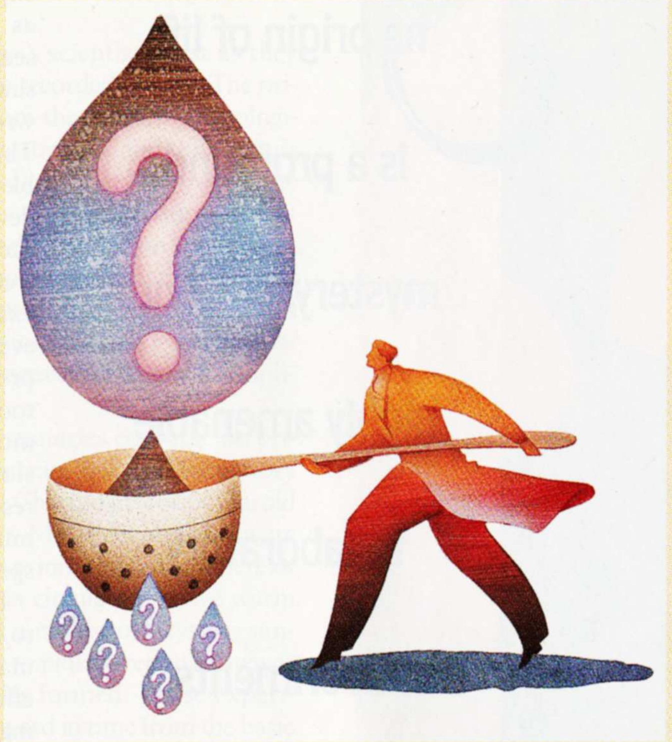
It may take centuries to learn many crucial details of the developmental processes that sculpt our faces, our bodies, and our minds, but a few underlying principles are beginning to emerge through remarkable laboratory experiments. This science, known as developmental biology, often seems peculiar to casual observers since it focuses largely on what goes wrong rather than what goes right. That's because it's almost impossible to track the genetic pathways of development when everything goes according to plan. Even if we could freeze the sequence of events and examine every embryonic cell at every step along the way, too many processes occur simultaneously and too many genes play a role. What's more, humans develop much too slowly—and the ethics of embryo research are too touchy—to make much progress studying our own species.

Developmental biologists, hoping to learn how humans develop normally, therefore concentrate their efforts on much simpler fast-breeding organisms that develop abnormally. The standard research strategy involves growing countless millions of short-lived animals, most often the fruit fly *Drosophila melanogaster*, with its convenient 10-to-14-day life cycle. Thousands of scientists spend their entire research lives working on the genetics and development of the fly, the most thoroughly studied of all complex organisms. (A simple species of flat worm, *Caenorhabditis elegans*, comes in a distant second, followed by small vertebrates such as zebrafish, frogs, and mice.)

Developmental biologists produce a high yield of mutant individuals by exposing breeding flies or their eggs to x-rays or mutagenic chemicals. When a new individual fails to develop, or when it develops with an obvious abnormality, the research team swoops down to identify which gene has gone awry. Step by painstaking step, as critical developmental genes are identified one by one, scientists are beginning to piece together the puzzle of how life develops. But as old mysteries are solved, new ones quickly arise, as demonstrated by the recent progress researchers have made in the following key areas:

❑ *Chemical controls in the egg*: The development of every complex organism begins long before the sex act, sometimes months or years before egg and sperm unite. For example, each egg must contain a suite of complex chemical messages to guide an embryo's initial formation. In flatworms, for instance, the egg's first cell division always results in a larger cell to the front and a smaller cell to the rear. Even if one of those two cells is removed, the next division again yields a

The Great Unanswered Questions



In *Why Aren't Black Holes Black? The Unanswered Questions at the Frontiers of Science,* Maxine Singer and I identify what we think are the 14 most compelling questions that fascinate today's scientists and drive their research. We started with a few topics—the origin of life, the nature of matter and forces, and the ultimate fate of the universe, for example—that we found, through informal surveys, appear on almost every scientist's list. We added questions related to new materials, energy, aging, and the environment based on the vast research efforts now being devoted to them. And, finally, we mixed in questions about the earth's deep interior, dark matter in outer space, and genetics that relate directly to our own research.

1. *WHAT IS DARK MATTER?* Evidence from rapidly rotating galaxies suggests that much of the mass of the universe—perhaps more than 90 percent—is different from familiar forms of matter. Can we learn to detect this elusive missing mass and study its properties?

2. *WHAT WILL BE THE ULTIMATE FATE OF THE UNIVERSE?* The Big Bang theory postulates that the universe has been expanding since the moment of creation, but gravity must be slowing that expansion. Will the expansion continue forever, or will the universe eventually begin to collapse back in on itself, ending in a "big crunch"?

3. *CAN WE DEVISE A THEORY OF EVERYTHING?* Subatomic particles and the forces they exert on each other display striking patterns that suggest deep underlying symmetries in nature. Physicists search for one sweeping theory that will account for the behavior of all matter and energy.

4. *HOW DO ATOMS COMBINE?* Atoms exhibit extraordinary properties when combined: fuzzy, blue, wet, and sweet describe collective properties unlike anything associated with individual atoms. Chemists continue to exploit empirical trends, theoretical computations, and trial-and-error methods in their quest for new materials.

5. *WILL WE RUN OUT OF ENERGY?* Energy is essential to all human pursuits, yet supplies of cheap and clean fuels are limited. The search for new energy sources, including those based on solar power and nuclear fusion, are forefront research priorities.

6. *WHAT'S GOING ON INSIDE THE EARTH?* The earth's dynamic interior helps to shape the planet's surface, and drives many of its most destructive natural disasters. Earth scientists combine seismic data and laboratory simulations in an effort to understand processes in the inaccessible deep interior.

7. *HOW MANY PEOPLE CAN THE EARTH SUSTAIN?* Many observers conclude that the human population, which at today's growth rates will exceed 25 billion by the mid-twenty-first century, is the greatest threat facing our future. The question of the maximum sustainable population is central to many of the earth's most pressing environmental concerns.

8. *HOW DID LIFE ON EARTH ORIGINATE?* Of all the age-old origin questions, the process by which life arose is the most amenable to study in the laboratory. Experiments, both on primitive single cells and on the prebiotic synthesis of organic chemicals, hold the promise for duplicating key steps in life's early history.

9. *CAN WE UNRAVEL THE GENETIC CODE?* All known life

larger and a smaller cell in the same orientation. In this way, in fact, the separation of head from tail occurs right from the start by a chemical signal in the egg. But the egg can't control development forever. After two cell divisions (four cells total) removal of any one cell will result in grievous deformity in the flatworm. Evidently, from that point on, the cells themselves send each other signals that guide development, but exactly how is the subject of further investigation.

❑ *Gene regulation*: The process by which a specific gene is triggered into producing or not producing a protein lies at the heart of developmental biology. Every cell of an organism contains the complete genome—the instructions for making every protein—yet cells perform remarkably specialized functions. The human pancreas, for example, is a composite of different types of cells that produce key chemicals including the hormone insulin and a variety of digestive enzymes. All cells in the pancreas carry all of the body's genes, but in each cell type only a limited number of spe-

forms employ the same genetic language, encoded by DNA and transcribed by RNA. Forefront research now focuses on understanding the roles of our 80,000 genes, and discovering ways of modifying DNA to fight disease and develop new organisms.

10. How did life on Earth become so varied? The evolution of life by natural selection is one of the most thoroughly documented theories in science, but many questions remain about the rate and mechanisms of the process. Biologists are trying to learn why competitive systems tend toward complexity, and to identify principles that underlie their development.

11. How do we develop from a single cell? One of the oldest mysteries in biology is the process by which a single cell, the fertilized egg, becomes a human being. Meticulous work on the developmental biology of flies, worms, and fish is providing tantalizing insights about our own development.

12. What are the physical origins of memory? The human brain is the most complex object known. While an understanding of consciousness still lies more in the realm of philosophy than science, we are beginning to address the physical nature of information storage in the brain.

13. Is behavior dictated by genes? Human behavior and genes are inextricably linked; many genetic disorders, for example, result in serious behavioral abnormalities. But the extent of the links between genes and behavior, and the modifying influences of environment, are still matters of intense study and contentious debate.

14. Are we alone in the universe? Of all deep questions about the universe, the possible existence of extraterrestrial life has the simplest answer: either we are alone, or we are not. Yet no question has more profound implications in the search for understanding about our place in the cosmos.

Other scientists may feel other unanswered questions are even more important, especially those related to their own work. In fact, any scientist who does not include his or her own research field in a list of top unanswered questions should consider switching fields. But whatever the list, it's important to note that it will change dramatically in the years ahead as now unimaginable questions come to light. Indeed, the most exciting part of the scientific drama is the continual discovery of phenomena that we didn't know we don't know.—*Robert Hazen*

cific pancreatic proteins are manufactured. Similarly, every cell contains the genes for producing the two proteins that constitute hemoglobin, but these genes are only expressed in red blood cells.

Scientists have discovered that a unique mix of chemical signals control every developmental step. But we have only just begun to uncover the secrets of how these signals regulate the development and processes of the thousands of genes in each cell of the body.

❑ *Programmed cell death*: Developmental biology is as much about cell death as it is about cell growth. As an embryo develops, exquisitely selective cell death sculpts embryonic pits, cavities, and tubes that will become major structures of the body. The cells that form the weblike tissues between developing digits, for example, all die at a certain time to leave isolated fingers and toes. In the brain, cells expire at enormous rates, leaving only those that have established productive, interacting networks. Programmed cell death also eliminates cells of the immune system that recognize and would attack our own molecules. And throughout life, programmed cell death serves the crucial role of controlling numbers of cells and helping excise damaged or defective cells. Learning how cells know when to die remains one of the central unanswered questions of developmental biology.

❑ *Assembly instructions*: Many creatures—flies, worms, fish, and people—rely on remarkably similar body plans. All these organisms, along with most other animals, have a front, a rear, and a long gut extending from one end to the other. In 1984, biologists working with—what else—the fruit fly noticed that a grotesque mutation that placed fully formed legs on the head in place of antennae coincided with a defect in a small DNA segment of a gene. This segment, called the "homeobox," a small protein that binds neatly to a specific DNA segment, regulates genes that are crucial to pattern formation, particularly recurrent patterns such as arthropod segments, fly-eye facets, and mammal vertebrae.

Nearly identical homeobox segments appear more than 100 times on the fly genome, each segment associated with a different key developmental gene. These homeoboxes and their associated genes cluster along two giant chromosomal sequences, each a staggering quarter-million base pairs long. Developmental biologists were amazed to discover that the physical order of these developmental genes along the chromosomes is the same as the front-to-back order of the segments in the fly embryo. When a homeobox is broken, the fly's assembly instructions are somehow scrambled.

But what really grabbed the biologist's attention was the subsequent discovery of nearly identical homeobox segments in all sorts of organisms, from worms to humans. The exact same genetic switch appears to operate in countless ways, triggering packets of genetic instructions that make all manner of anatomical structures, from teeth to toes.

The implications of this discovery are vast. For a time it seemed as if every step of the developmental process was a special case, dependent on its own unique blend of genetic signals. Discovery of the universal role of the homeobox confirms what many biologists had hoped—that general principles underlie the details, and that exhaustive research on fruit flies and other animals has direct bearing on human development.

In fact, both the general principles and many of the specific steps observed in fly development shed light on the much more complex and inaccessible process in humans. For example, some scientists now suspect that defects in these homeobox control sequences may be responsible for many birth defects and spontaneous abortions in humans.

Moreover, if we can someday crack this code, patients may be able to regenerate their own damaged kidneys or lungs from a single healthy cell. Victims of brain and spinal-cord injuries might be coaxed into producing new neurons and nerve cells. And we might be able to target and suppress cancer cells, whose genetic instructions have gone awry. The instructions to set things right are deeply buried within each of us; we need only learn to read them.

As scientists delve further into the details of human development, aging, and death, we begin to glimpse how the unanswered questions related to human development and health are not and cannot be confined to science alone. Scientists, along with the rest of society, must ask what we should do with information about a genetic predisposition to disease. How will people cope with such information? Who should have access to such information? How will it be used, and how will we protect individuals from genetic discrimination?

As we learn to read and interpret our genetic scripts, we must recognize that each and every one of us brings into this world a set of genetic predispositions that we did not choose. We must ask ourselves how strictly determinative these scripts are, and whether and how we can modify their outcomes by behavior, diet, or medicine. These social and ethical issues remain as compelling a set of unanswered questions as the pathways of cell development and death.

Clearly, even the most cursory review of today's most compelling scientific questions promises centuries of research adventure and discovery. We have yet to answer the mystery of dark matter in outer space, understand the astonishing origin of life, unravel the unimaginably complex development of you and me from single cells, and explore a thousand other questions both asked and as yet unasked.

Critics such as John Horgan divide science into neat little pieces: the end of physics, the end of cosmology, the end of evolutionary biology, as if scientific knowledge comes in a few little parcels that can be hermetically sealed and put aside when complete. Nature knows no such boundaries. Physics is a part of cosmology is a part of geology is a part of life. The most exciting questions awaiting future scientists will arise not at the centrum of established knowledge, but at the unexplored interfaces of traditional academic disciplines. Profound unanswered questions about the environment, evolution, and the diversity of life in the universe span traditional boundaries and require new modes of thought and strategies for answering them.

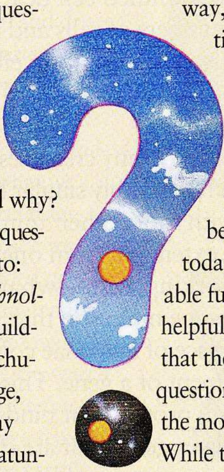
The more our knowledge grows, the more we realize how much we don't know. We almost certainly have yet to recognize and ask many of the most profound questions about the universe. The true measure of scientific progress is thus not so much a catalog of the questions we can answer as the list of questions we have learned to ask. And as far ahead as anyone can foresee, the questioning will not end. ❑

TECHNOLOGY REVIEW

READER SURVEY

What Do You Want to Know?

ROBERT HAZEN AND MAXINE SINGER have identified what they believe are the 14 most profound questions in science today. Do you agree with their list? What questions would you add or subtract, and why?



Please send your questions and comments to: Reader Survey, *Technology Review*, MIT Building W59, 77 Massachusetts Ave., Cambridge, MA 02139. You may also e-mail us at greatunknown@mit.edu, or respond to the online version of this article on our Web page at http://web.mit.edu/ techreview/. We will forward the responses to Robert Hazen and Maxine Singer, who will tabulate the results and summarize your ideas for publication in a future issue of *Technology Review*.

A few thinkers besides Hazen and Singer have been emboldened to offer their personal lists of the most fundamental scientific questions. For example, Paul Davies, a theoretical physicist at the University of Newcastle-Upon-Tyne in the UK, identifies "the Big Four questions of existence: Why are the laws of nature what they are? Why does the universe consist of the things it does? How did those things arise? How did the universe achieve its organization?" Though profound, these questions are at least one step removed from the kind of inquiry that scientists can pursue in any systematic way, through observation and experiment.

In formulating your questions, please consider those that you think science could begin to address today or in the foreseeable future. It may also be helpful to bear in mind that the most profound questions are not always the most obvious ones. While the ultimate fate of the universe, the origin of life, and the inevitability of aging and death have intrigued us for thousands of years, other compelling questions, such as the nature of energy, the control of genes, and the mystery of dark matter, are far more subtle, emerging gradually from the nagging persistence of odd observations and anomalous bits of data collected over decades or even centuries.

Finally, don't feel compelled to ask questions that involve long, complex answers. An exhaustive multivolume catalog of all the world's mammals, though useful, would likely provide few fundamental new insights, while an unambiguous "yes" or "no" answer to the question of whether intelligent life exists on other worlds would be as profound as any discovery in history. ❑

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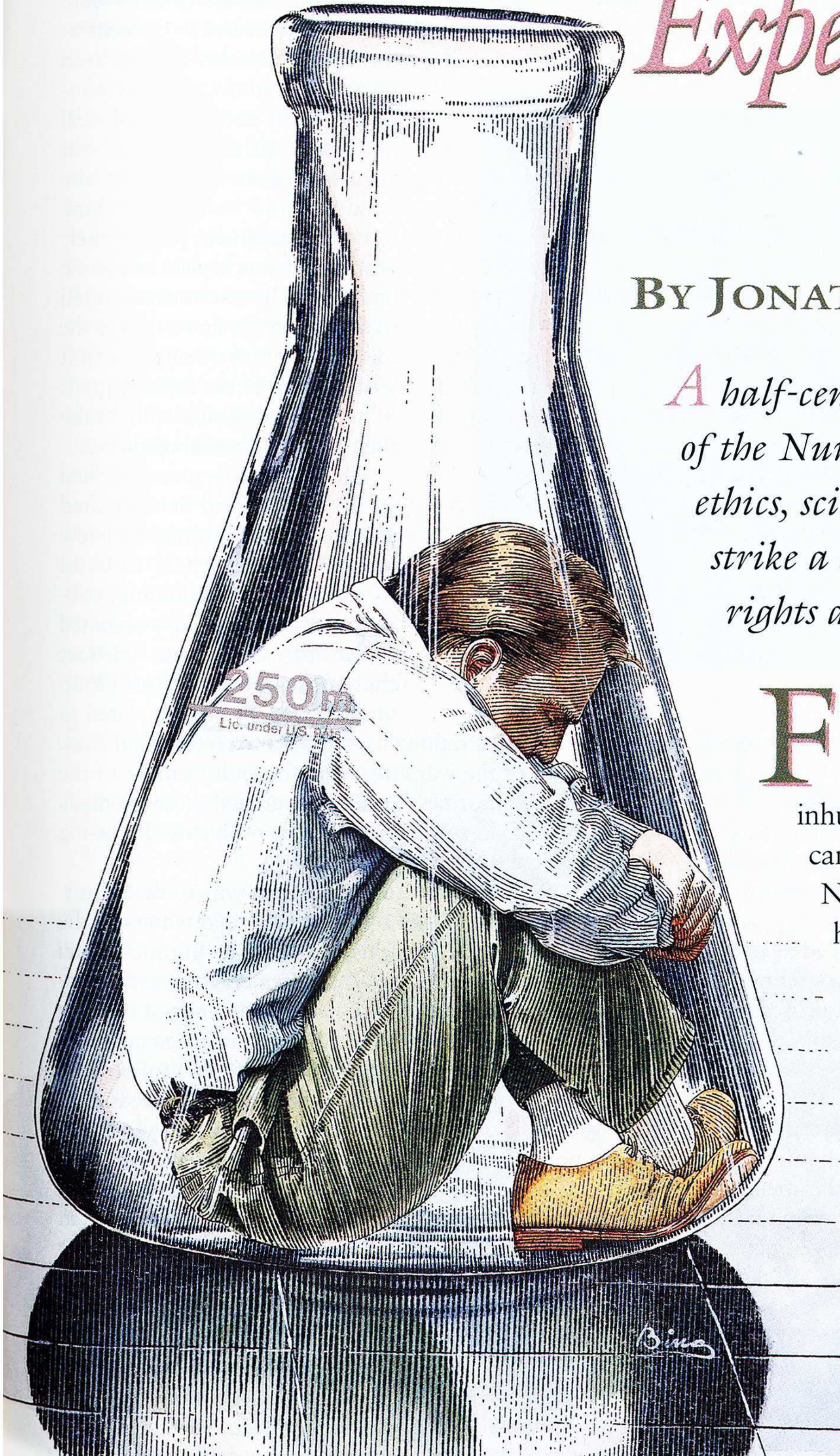
The Dilemmas of Experimenting on People

BY JONATHAN D. MORENO

A half-century after the creation of the Nuremberg Code of research ethics, scientists still struggle to strike a balance between human rights and medical progress.



FIFTY years ago this summer, the trial of 23 Nazi doctors and medical scientists for performing cruel and inhuman experiments on concentration-camp inmates led to the creation of the Nuremberg Code, a milestone in the history of medical ethics. The first line of the code, "The voluntary consent of the human subject is absolutely essential," is generally regarded as the sine qua non for the ethical conduct of research. During the past year, institutions throughout the United States and Europe have been sponsoring events to celebrate the Nuremberg Code as a bulwark of human decency in the pursuit of scientific knowledge.

ILLUSTRATIONS: CHRISTOPHER BING

Although the ideals it embodies are now viewed as unassailable, the code was initially greeted by medical scientists as poorly conceived and unrealistic. For decades, it only sporadically influenced research ethics in policy or in practice; many doctors and scientists resisted applying the principle of informed consent to their own work. The code's uneven influence can be attributed to the extreme circumstances of its origin, the culture of medicine at the time, and the broad phrasing its authors employed. Like so many ethical maxims ("Love thy neighbor as thyself"), the principle of voluntary informed consent seems uncomplicated. Yet 50 years after it was first articulated, we are still struggling to live up to it.

Confident of their sound motivations, mainstream medical practicioners did not see how their actions could fall into the same ethical category as those of the Nazi doctors.

To Do More Than Hand Down Judgments

THE war crimes trial of the Nazi doctors that led to the code was held in Nuremberg, West Germany, from December 1946 to August 1947. Nuremberg was chosen partly for symbolic reasons, for it was there that the Nazi Party held giant, theatrical rallies designed both to impress those faithful to the Reich and to intimidate those who opposed it.

The doctors' trial began a few months after the conclusion of proceedings against two dozen leaders of the Third Reich, including Hermann Goering, Rudolf Hess, and Joachim von Ribbentrop. Although the American forces occupying Germany had not at first planned to conduct an inquest on human experimentation, their decision changed as information emerged about the medical atrocities committed in the concentration camps. The details of what prosecutors called "the medical case" so shocked them that they decided to pursue the matter as a war crime under the charter of the international tribunal.

Medicine had a central place in the Nazi enterprise, for the Nazis believed doctors had a special role in improving the "Volk." Jews, Gypsies, homosexuals, the mentally retarded, and others were singled out as corrupting influences in the German national body, much like bacteria invading the individual. The view that these groups constituted a kind of public health menace implied an instrumental role for the medical profession in the business of "diagnosing" and "treating" the problem.

Although many doctors were involved in the Nazis' racial hygiene policies—and nearly half of German doctors were Nazi party members—those who had access to concentration camp inmates for research purposes had to be well connected with the Nazi political hierarchy. Although we are not accustomed to thinking of the Nazi doctors in the mundane terms of careerism, part of their motivation was typical academic ambition. These scientists wanted to be among the first to make the medical breakthroughs that would advance the military goals of the Third Reich and make them heroes of racial medicine.

The special role given medical science in the Third Reich created an excellent opportunity for a few influential researchers to avail themselves of experimental subjects they could not have obtained under other conditions. The fact that most concentration camp inmates were eventually slated to die helped doctors rationalize their use as research subjects. The urgency of the war effort and the endorsement of the highest state authorities further encouraged these scientists to perform human-subjects research on problems of pressing concern on the battlefield.

One of these was the most efficacious way to thaw Luftwaffe fliers forced to bail out over the frigid waters of the North Sea. To test various thawing techniques Nazi researchers exposed a number of prisoners to freezing conditions and experimented with various methods of reviving them. Other experiments for military purposes included forcing subjects to drink only seawater to determine how long pilots could survive once downed in the ocean and establishing the point at which lungs exploded due to atmospheric pressures, an important issue for fighter pilots seeking to avoid anti-aircraft fire. An estimated 100,000 human beings died horrible deaths in the course of experiments at Auschwitz, Buchenwald, Dachau, Sachsenhausen, and other camps.

The brief against the defendants was delivered on December 9, 1946, by chief prosecutor Telford Taylor. In his opening statement, Taylor declared that the men were on trial for "murders, tortures, and other atrocities committed in the name of medical science." But the prosecutors soon discovered that the case raised issues that were more problematic than they had realized—among them the lack of interna-

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tionally recognized codes of medical ethics by which the behavior of the Nazi doctors could be judged. Nonetheless, nearly eight months later, after harrowing testimony about the experiments by surviving victims, the Nuremberg judges sent seven of the defendants to their deaths and sentenced eight more to lengthy prison terms. (None of those who were imprisoned served a full sentence, and many went on to distinguished careers in postwar Germany.)

The three-judge panel decided that it needed to do more than simply hand down the judgments. The members decided to codify the rules they believed should govern the use of human beings in all medical research. The Nuremberg Code begins: "The voluntary consent of the human subject is absolutely essential. This means that the person involved should ... be so situated as to be able to exercise free power of choice, without the intervention of any element of force, deceit, duress, over-reaching, or other ulterior form of constraint or coercion." The code also included provisions requiring that the scientific importance of the question be manifest, that risks to the subjects be kept to a minimum, and that prior experimentation be performed on animals.

Despite its powerful moral influence, the code carried no legal authority. No mechanisms were created to enforce it. In fact, the very circumstances that gave the code its high moral standing—the horrors that surrounded its origins—partly account for its relative lack of influence in the postwar years: ordinary researchers found it hard to believe that the code need be applied to their own work.

Extraordinary Circumstances

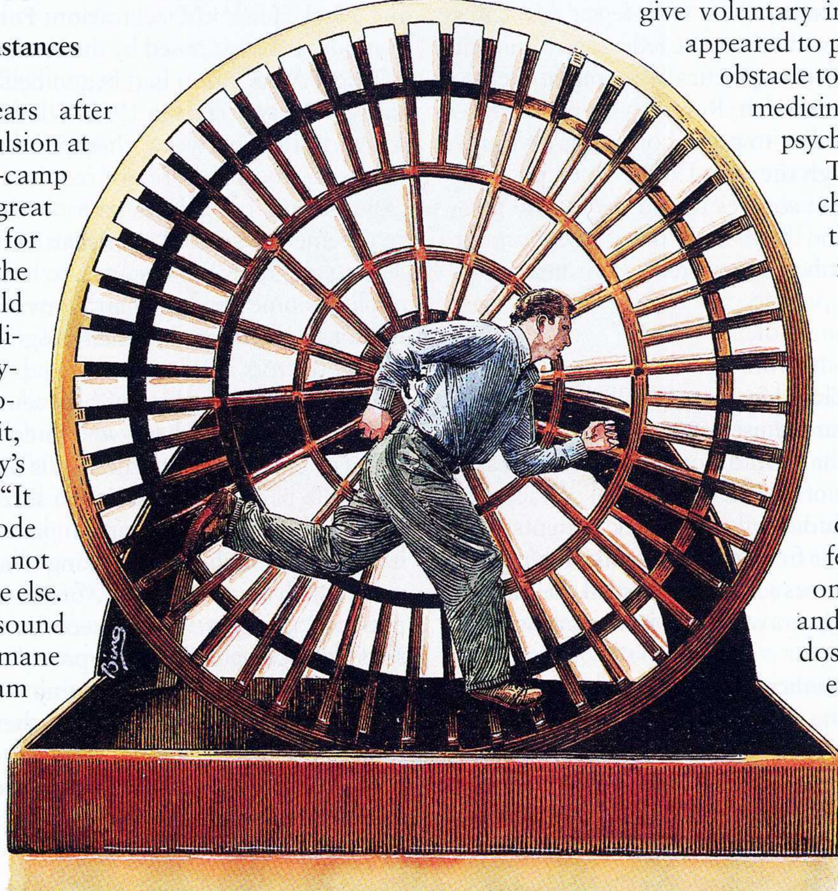
In the early years after Nuremberg, revulsion at the entire death-camp phenomenon was so great that it was difficult for many to see how the Nuremberg Code could apply to normal conditions. As the Yale psychiatrist and law professor Jay Katz put it, the medical community's general attitude was, "It was a good ethics code for barbarians." But not necessarily for everyone else. Confident of their sound motivations and humane instincts, mainstream medical practitioners felt they were inoculated against the evil that had infected the Nazi doctors. That their actions might fall into the same ethical category was difficult for most such practitioners to conceive.

The fact that the Nazi experiments occurred during wartime also made the code seem remote from the conduct of peacetime research. Although the Nuremberg judges utterly rejected national-security concerns as a rationale for the medical experiments, ordinary people may have viewed these crimes less as the actions of culpable individuals than as the result of specific national policies. While governments at war might order such extreme and brutal measures, surely few individuals would do such a thing on their own initiative.

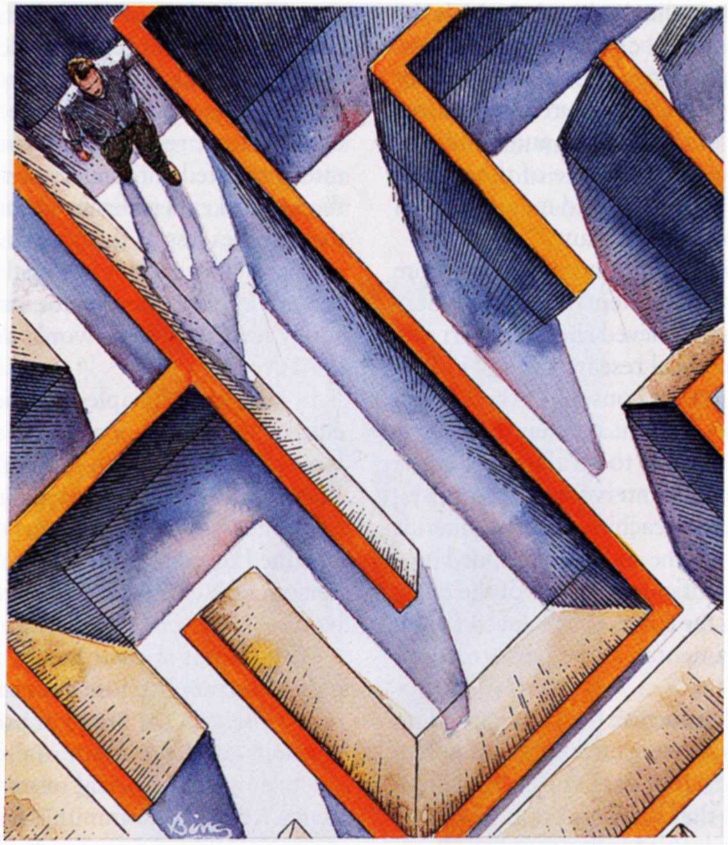
In fact, the principle of informed consent was far from entrenched in American medical practice at the time. Most large-scale research on human subjects, spurred by World War II, was conducted by the military on institutionalized "volunteers"—conscientious objectors, prisoners, people confined to mental institutions, or, in rare cases, military personnel. Researchers preferred institutionalized subjects because it was easier to monitor them.

Although it is clear in retrospect that the Nuremberg judges purposely chose to enshrine the principle of voluntary consent in the broadest possible terms, the very sweep of their language made the code seem poorly crafted. According to historical research conducted by the President's Advisory Committee on Human Radiation Experiments in 1994, what struck many medical researchers as especially unrealistic was the code's seemingly categorical ban on research with any subjects who could not give voluntary informed consent. This appeared to pose an insurmountable obstacle to progress in key areas of medicine such as pediatrics and psychiatry.

The issue of research on children was an especially thorny one. Some of the most important medical research in history has been aimed at conquering childhood diseases, particularly by developing vaccines. Researchers had to experiment on children in order to ensure the effectiveness of the vaccine on its target population and determine the proper dosage. Some of these experiments were of enormous benefit to their subjects as well as to future generations of children. Nonetheless,



it was widely recognized that children are not capable of granting consent. The question confronting researchers, then, was whether the authors of the code intended to abandon this whole field of research, even at the cost of saving children's lives.



The by-now-familiar solution was to establish parental permission as the moral equivalent of the child's consent, on the grounds that parents will act in the best interest of the child. Although obtaining parental consent became standard practice by the late 1950s, it was not required by federal regulations until the late 1970s. This resolution extended to the most vulnerable members of society the principal lesson of Nuremberg.

However, not all of society's vulnerable members were equally well protected. Because there were fewer advocates for the mentally ill than for children, the federal government has never enacted regulations specifically targeting the use of psychiatric patients in research. Research on prisoners—another group whose ability to grant consent is compromised—continued through the mid-1970s, when political pressures from a variety of sources forced the federal government to declare a halt on the grounds that consent cannot be truly voluntary in an inherently coercive environment.

The Doctor Knows Best

PHYSICIANS in the United States gradually became willing to concede that the use of unconsenting subjects in experiments that could not benefit them was a dangerous encroachment of science on personal privacy. But therapeutic research—studies involving sick patients who might in some way benefit from experimental treatment—was a different story. Doctors jealously guarded the "therapeutic privilege," the right to withhold information from patients.

Although the field of medicine was changing rapidly, the culture of medical practice still operated largely on an old-fashioned, paternalistic model. According to this view, the trusting, nearly sacred relationship between doctor and patient was based on the premise that the doctor knows best; a good patient was defined as a compliant one. Even if the physician's care involved the use of experimental drugs or devices as part of a scientific study, doctors were reluctant to involve patients in making decisions about their own care.

Nothing symbolized doctors' fears of intrusion into their relationships with patients more than consent forms. In the early 1950s consent forms were used in certain exceptional cases (such as invasive procedures that simply could not be performed without a patient's knowledge and cooperation) but not in the vast bulk of therapeutic research. For the most part, the privacy of the doctor-patient relationship was accepted as serving the public interest.

The philosophy of medical paternalism was codified in the 1964 Helsinki Declaration. Partly in response to the consent problems posed by the Nuremberg Code, the World Medical Association had begun deliberations to formulate its own research code in 1953. The resulting document drew a sharp line between therapeutic and nontherapeutic research; doctors were not required to obtain consent for experimental procedures performed on their patients if this requirement was not "consistent with patient psychology." This might apply, for instance, to terminally ill patients who could become depressed and unwilling to undergo further treatment if informed of their prognoses.

Few doctors involved in research in the 1950s paused to reflect on the contradictions between their own roles as caregivers and as researchers—the so-called double-agent problem. For example, from the 1940s through the early 1960s, scientists performed a series of secret, government-sponsored radiation experiments on patients who were hospitalized, institutionalized, or seeking treatment for other conditions (such as pregnancy), often without obtaining the patients' consent. When records of these experiments recently became public, they provoked widespread outrage. At the time, however, there was no mechanism requiring scientists to obtain consent from their subjects. And even though the researchers must have been aware of the existence of the Nuremberg Code, it is doubtful that they felt its provisions applied to research conducted in the context of the doctor-patient relationship.

An Emerging Consensus on Consent

TOGETHER these factors worked against implementing the consent requirement of the Nuremberg Code in any formal or consistent fashion in the first decade after it was articulated. But in the early 1960s a wave of medical scandals brought the issue of informed consent to the fore. In 1963, a university team conducted a well-publicized but medically doomed effort to transplant a chimpanzee kidney into a human patient—an experiment conducted partly with federal funds, but without prior animal studies or valid scientific justification. The episode heightened concern about the lack of scientific or government oversight of research using human subjects.

A few years later, Harvard anesthesiology professor Henry Beecher, in an article in the *New England Journal of Medicine*, claimed to have found 22 obvious abuses of human subjects in the recent medical literature. In one of these cases, researchers injected live cancer cells into debilitated patients at the Brooklyn Jewish Chronic Disease Hospital without the subjects' knowledge in order to determine whether their immune systems could mount a defense against the cancer. (The subjects were not harmed by the experiment.)

In 1966, the surgeon general announced a policy to govern human-subjects research supported by Public Health Service grants. It required institutions receiving PHS support to create an institutional review board to oversee research involving human subjects and demanded that researchers obtain consent from their subjects.

But if a single event broke the back of medical paternalism in research it was surely the Tuskegee syphilis study. From the early 1930s to the early 1970s, U.S. Public Health Service doctors had studied more than 400 black men with syphilis in Macon County, Ala. The men were not told they had the disease, nor were they offered treatment—even after the discovery of penicillin made treatment much more effective. When a journalist broke the story, a firestorm of outrage swept the country. The requirement for the "voluntary consent of the human subject" had been systematically abused right here in America, in a study that had begun just around the time the Nazis took power in Germany.

The federal government appointed a commission to investigate the scandal in 1972. Recommendations based on its findings, released in 1978, were incorporated into Department of Health and Human Services regulations in 1981 and extended to all federal agencies conducting or sponsoring human-subjects research in 1991. As a result of the Tuskegee scandal, the requirement for voluntary consent in research became deeply etched in the law and in the minds of many who had not seen the need for vigilance before.

The question confronting researchers was whether the authors of the Nuremburg Code intended to abandon research on children even of it would help save their lives.

The Code Today

ALTHOUGH it took decades to gain wide acceptance, the Nuremberg Code exerts a profound influence on the conduct of medical research today. An excellent example is the recent ruling by the Food and Drug Administration (FDA) governing research in the emergency room.

Because standard treatments for some conditions, such as head injuries, are ineffective, doctors want to try experimental drugs and devices that they consider promising, based on laboratory work and animal testing. But many emergency room patients suffering from these conditions are unconscious and relatives may not be present. The inability to obtain consent has slowed the pace of vitally needed research.

The FDA ruling permits researchers to enroll patients with life-threatening conditions in certain studies even if they are unable to grant voluntary informed consent, but only if they have informed the community that such studies are going on and that anyone who is admitted to the emergency department with a serious condition could be assigned as a subject. While media accounts have portrayed the FDA decision as a step back from the principle of informed consent, the fact that the agency had to make an explicit exception shows the tenacity with which we now embrace it. The ruling represents one step in the continuing effort to walk the fine line between medical progress and human rights.

The Nuremberg Code also contributed to a sea change in public attitudes toward research, which in turn has spurred debate over access to experimental treatments. It took decades to develop a consensus within the medical community that even ordinary science conducted by well-meaning researchers can lead to unintended harm. Today a system of carefully designed regulations protects desperate people from medical experiments that might only make them worse. In fact, the protections built into the system are so successful that people have become confident of low

risks and high benefits if they are granted access to experimental drugs.

In the 1980s, AIDS activists mounted a series of successful campaigns to broaden access to experimental drugs such as AZT. Similarly, women of reproductive age, who were systematically excluded from many drug trials following the thalidomide tragedy of the early 1960s, have sought to participate equally in research in order to capture the potential benefits of experimental treatments and ensure that drugs or devices are developed to meet their needs. For instance, women excrete medications at different rates than men, and since women are more likely than men to use prescription drugs, advocates have argued that they should be better represented in research studies.

Today, concern about informed consent in medical research is greater than ever. In response to the uproar over the Cold War radiation experiments, President Clinton recently announced that henceforth all secret human research conducted in the name of national security would be subject to the rules of informed consent, and that scientists would reveal the names of the sponsoring agencies to participants. What's more, Clinton's advisory commission on bioethics, appointed last year, will undertake a review of current practices and requirements regarding the use of human subjects. In particular, the commission should address ways to ensure that voluntary consent is meaningful.

For instance, there is evidence that seriously ill patients often overestimate the likelihood that they will benefit from experimental treatments. Early trials of a new drug may be designed to determine its effects on the body, such as the rate at which it is excreted—not whether or not it is likely to cure the patient. In fact, most experimental treatments don't work. In order for consent to be truly voluntary, the commission should require that sick patients receive counseling to ensure they understand the implications of research for themselves.

Another issue confronting the commission is whether states should enable people to declare in advance of a serious illness and loss of capacity their willingness to be a research subject in a study that might help them. At least some people who may be candidates for emergency-room research might be willing to make such an advance declaration. This measure would enable researchers to continue to investigate experimental emergency-room treatments without relying so heavily on unconsented research.

The principle of informed consent continues to pose new dilemmas for medical science. It is not always easy to find the balance between human rights and scientific progress. Yet the simplicity and intuitive force of the ideas articulated in the Nuremberg Code ensure their lasting moral relevance.

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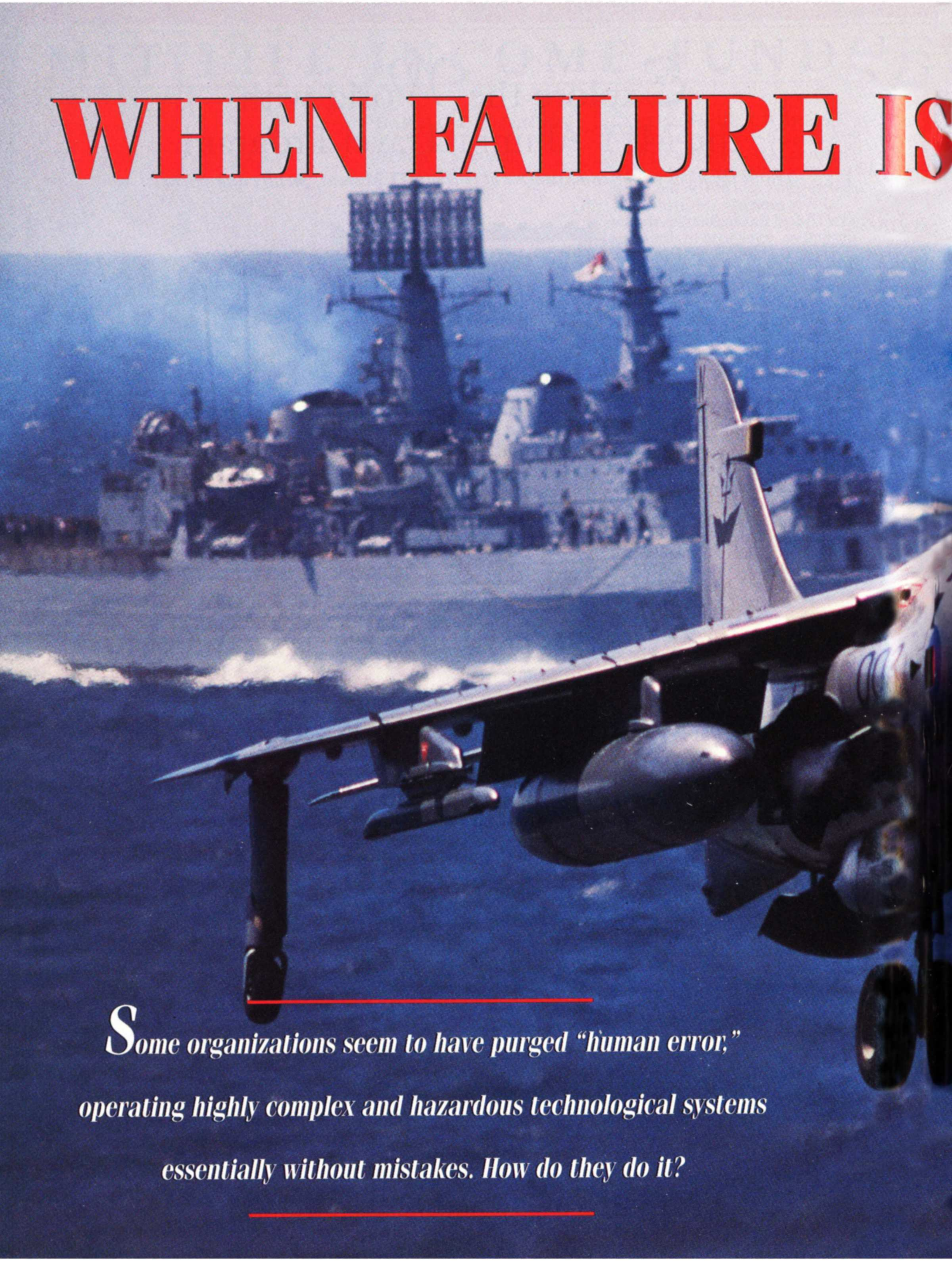
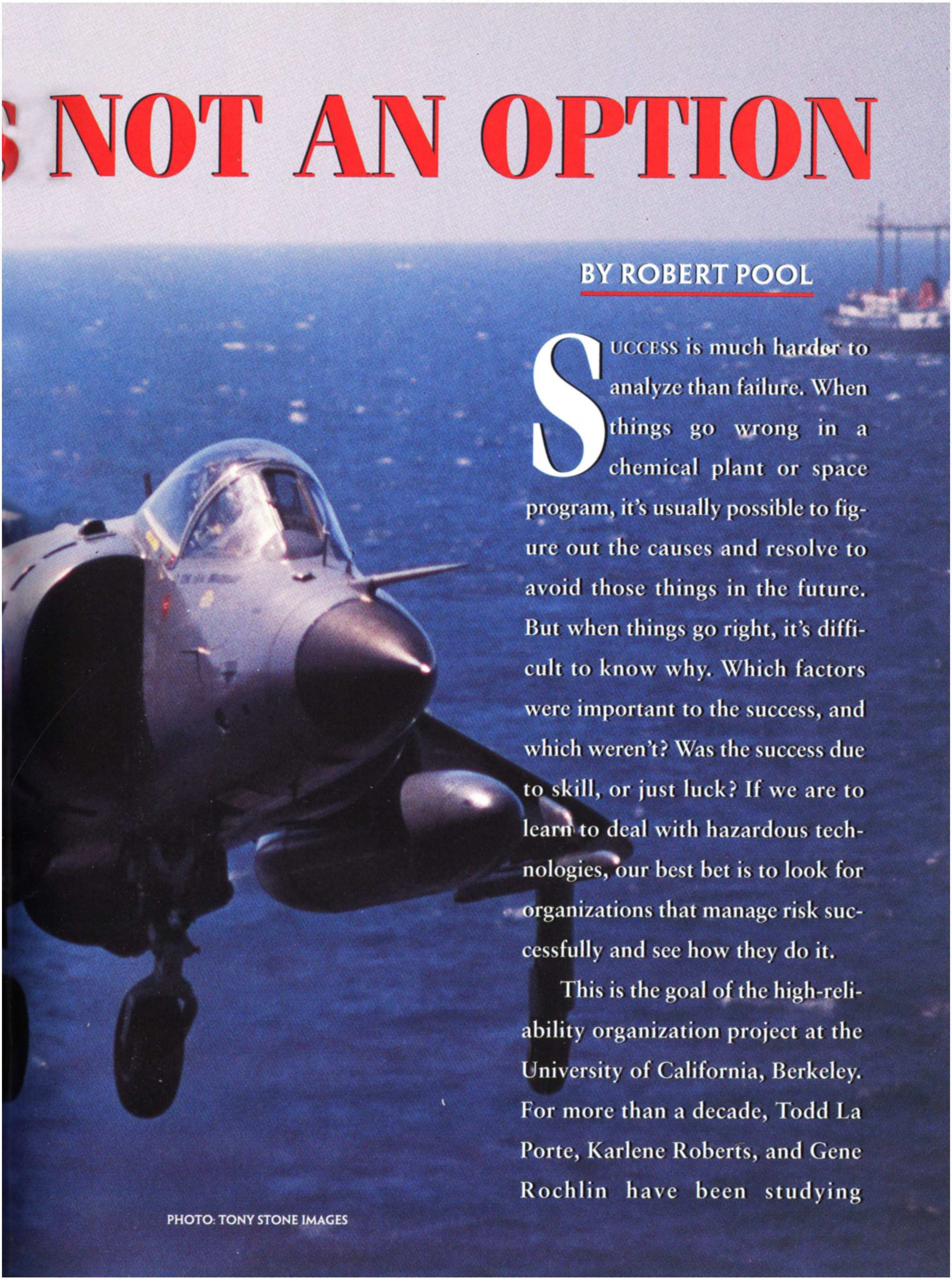
WHEN FAILURE IS



Some organizations seem to have purged "human error," operating highly complex and hazardous technological systems essentially without mistakes. How do they do it?



S NOT AN OPTION

BY ROBERT POOL

SUCCESS is much harder to analyze than failure. When things go wrong in a chemical plant or space program, it's usually possible to figure out the causes and resolve to avoid those things in the future. But when things go right, it's difficult to know why. Which factors were important to the success, and which weren't? Was the success due to skill, or just luck? If we are to learn to deal with hazardous technologies, our best bet is to look for organizations that manage risk successfully and see how they do it.

This is the goal of the high-reliability organization project at the University of California, Berkeley. For more than a decade, Todd La Porte, Karlene Roberts, and Gene Rochlin have been studying

PHOTO: TONY STONE IMAGES

groups that seem to do the impossible: operate highly complex and hazardous technological systems essentially without mistakes. The U.S. air traffic control system, for instance, handles tens of thousands of flights a day around the country. Air traffic controllers are not only responsible for choreographing the takeoffs and landings of dozens or hundreds of flights per hour at airports but also for directing the flight paths of the planes so that each keeps a safe distance from the others. The success is unequivocal: for more than a decade none of the aircraft monitored on the controllers' radar screens has collided with another. Yet the intricate dance of planes approaching and leaving airports, crisscrossing one another's paths at several hundred miles an hour, creates plenty of opportunity for error. This record of safety is not due to extremely good luck, the three Berkeley researchers conclude, but to the fact that the institution has learned how to deal effectively with a complex, hazardous technology.

Perhaps the most impressive organizations they have studied are the nuclear aircraft carriers of the U.S. Navy. While it's impossible for anyone who hasn't worked on such a ship to truly understand the complexity, stress, and hazards of its operations, this description by a carrier officer to the Berkeley researchers offers a taste:

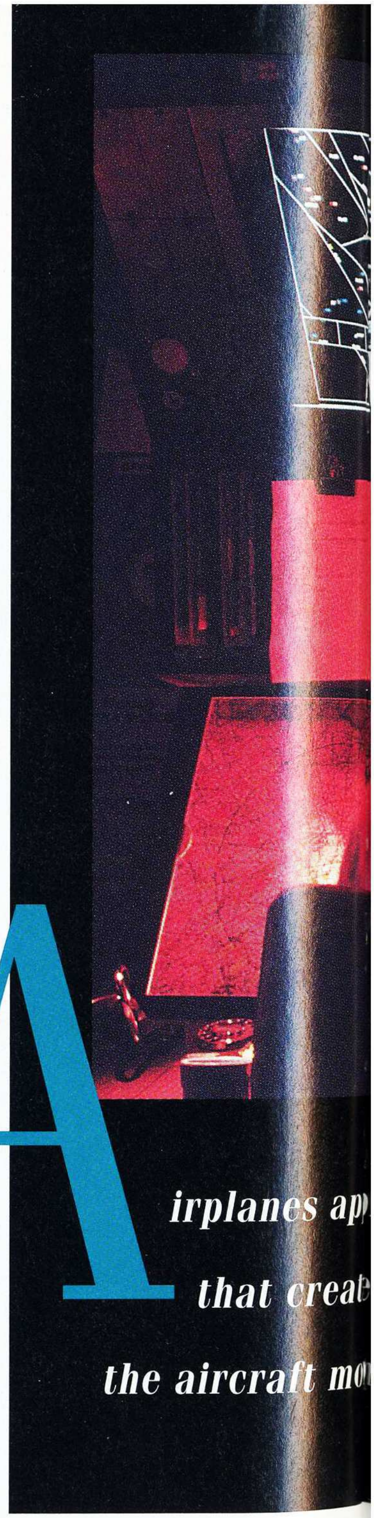
> So you want to understand an aircraft carrier? Well, just imagine that it's a busy day, and you shrink San Francisco Airport to only one short runway and one ramp and gate. Make planes take off and land at the same time, at half the present time interval, rock the runway from side to side, and require that everyone who leaves in the morning returns that same day. Then turn off the radar to avoid detection, impose strict controls on radios, fuel the aircraft in place with their engines running, put an enemy in the air, and scatter live bombs and rockets around. Now wet the whole thing down with salt water and oil, and man it with 20-year-olds, half of whom have never seen an airplane close up. Oh, and by the way, try not to kill anyone.

A Nimitz-class carrier flies ninety aircraft of seven different types. These aircraft have only several hundred feet in which to take off and land instead of the mile or more available at commercial airports, so they need help. At takeoff, the planes are catapulted by steam-powered slingshots that accelerate them from standstill to 140 knots (160 miles per hour) in just over two seconds. As each plane is moved into place on the steam catapult, crewmen check it one last time to make sure that the control surfaces are functioning and that no fuel leaks or other problems are visible. The catapult officer sets the steam pressure for each launch depending on the weight of the plane and wind conditions. The spacing of the launches—about every 50 seconds—leaves no time for errors.

But it is the recovery of the planes that is truly impressive. They approach the flight deck at 120 to 130 knots with a tail hook hanging down to catch one of four arresting wires stretched across the deck. As a plane approaches, the pilot radios his or her fuel level. With this information, the people in charge of the arresting gear calculate the weight of the plane and figure the proper setting for the arresting-gear braking machines. If the pressure is set too low, the plane may not stop soon enough and so topple off the end of the deck into the sea. If the wire is too taut, it could pull the tail hook off or else snap and lash out across the deck, injuring or killing anyone in its path. The pressure for each of the four wires is set individually by a single seaman.

Meanwhile, landing signal officers are watching the approach of the plane, advising the pilot and then—if everything appears right—okaying the landing. Just as the plane touches down, the pilot gives it full throttle so that if the hook does not catch, the plane will be going fast enough to take off and come around again. If the hook does catch a wire, the plane is slammed to a halt within about two seconds and 300 feet. As soon as the plane is down and stopped, "yellow shirts" rush to it to check the hook and to get the plane out of the way of the next one. As the arresting wires are pulled back, other crewmen check them for frays. Then it all begins again. The cycle has lasted about 60 seconds.

The launching and recovery are only part of a much larger process including maintenance, fueling and arming, and maneuvering and parking the planes on a crowded deck. What makes the process all so truly astonishing is that it is done not with people who have been working together for years but with a crew that turns over regularly. As writer John Pfeiffer observed, "The captain will be aboard for only



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ROBERT POOL is a science writer based in Arlington, Va. This article is excerpted from Beyond Engineering: A New Way of Thinking About Technology, *published in June by Oxford University Press.*

PHOTO: WESTLIGHT

roaching and leaving airports crisscross paths in an intricate dance

s plenty of opportunity for error. But for more than a decade, none of

nitored on controllers' radar screens has collided.

three years, the 20 senior officers for about two and a half; most of the more than 5,000 enlisted men and women will leave the Navy or be transferred after their three-year carrier stints. Furthermore, they are predominantly teenagers, so that the average age aboard a carrier comes to a callow 20."

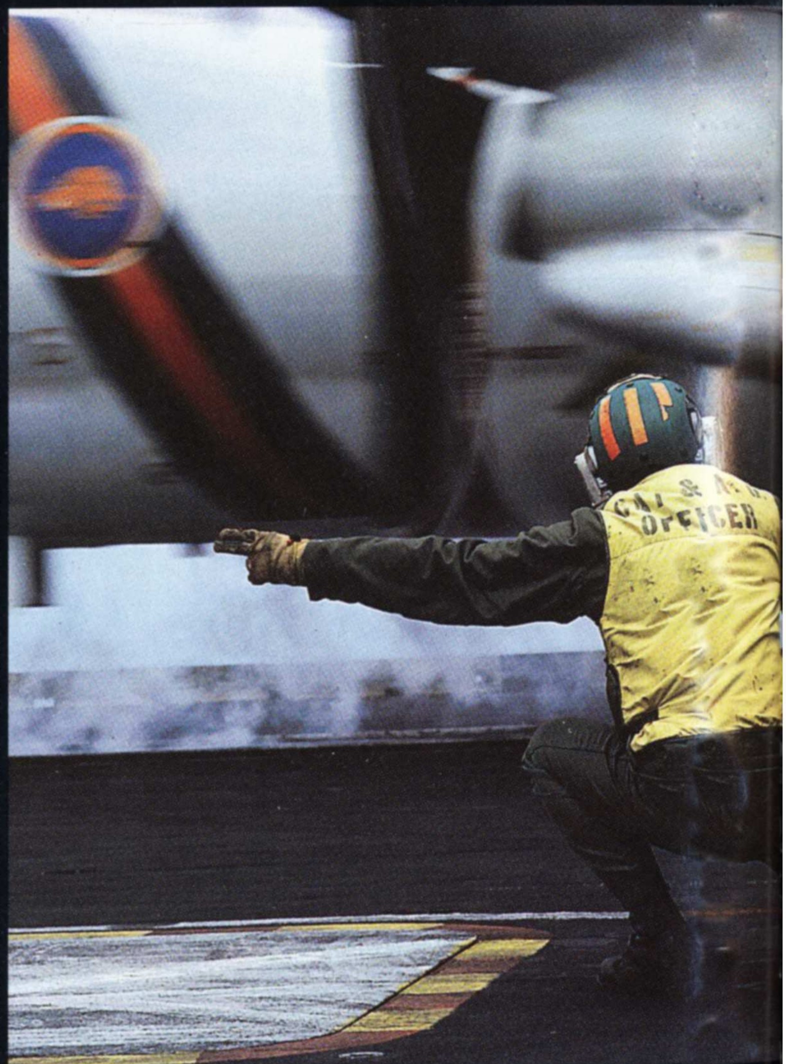
What sort of organization can operate so reliably under such handicaps? La Porte, Roberts, and Rochlin spent a great deal of time on several carriers both in port and at sea, during training and on active duty, and they believe they understand at least part of the answer.

On the surface, an aircraft carrier appears to be organized along traditional hierarchical lines, with authority running from the captain down through the ranks in a clearly defined pattern. And indeed, much of the day-to-day operation of the ship does proceed this way, with discipline rather strictly enforced. Thick manuals of standard operating procedures govern this process, and much of the navy training is devoted to making them second nature. These procedures codify lessons learned from years of experience. But, as the Berkeley researchers discovered, the carrier's inner life is much more complicated.

When things heat up, as during the launching and recovery of planes, the organizational structure shifts into another gear. Now the crew members interact much more as colleagues and less as superiors and subordinates. Cooperation and communication become more important than orders passed down the chain of command and information passed back up. With a plane taking off or landing once a minute, events can happen too quickly for instructions or authorizations from above. The crew members act as a team, each watching what others are doing and all of them communicating constantly through telephones, radios, hand signals, and written details. This constant flow of information helps flag mistakes before they've caused any damage. Seasoned personnel continuously monitor the action, listening for anything that doesn't fit and correcting a mistake before it causes trouble.

A third level of organizational structure is reserved for emergencies, such as a fire on the flight deck. The ship's crew has carefully rehearsed procedures to follow in such cases, with each member assuming a preassigned role. If an emergency occurs, the crew can react immediately and effectively without direction.

This multi-layered organizational structure asks much more from the crew than a traditional hierarchy, where following orders is the safest path and underlings are not encouraged to think for themselves. Here, the welfare of the ship and crew is everyone's responsibility. As the Berkeley researchers note, "Even the lowest rating on the deck has not only the authority, but the obligation to suspend flight operations immediately, under the proper circumstances and without first clearing it with superiors. Although his judgment may later be reviewed or even criticized, he will not be penalized for being wrong and will often be publicly congratulated if he is right."

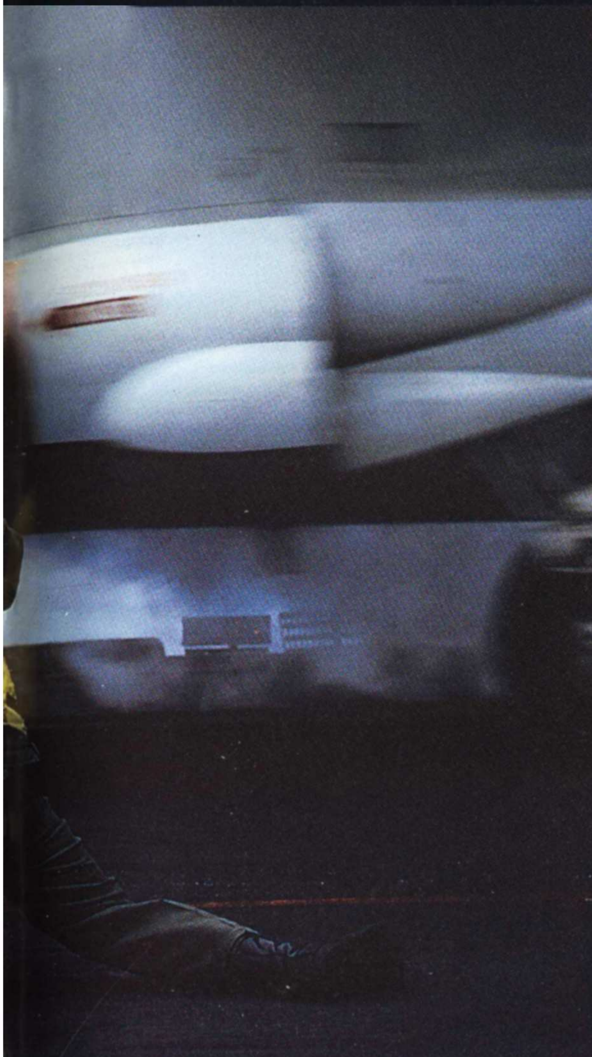


On a naval aircraft carrier, events instructions from above. Even t can suspend operations immedi ship and crew to be at stake.

The involvement of everyone, combined with the steady turnover among the officers and crew, also helps the Navy prevent such operations from becoming routine and boring. Because of the regular coming and going of personnel, people on the ship are constantly learning new skills and teaching what they've learned to others. And although some of the learning is simply rote memorization of standard operating procedures, the Berkeley researchers found a constant search for better ways of doing things. Young officers come on board with new ideas and find themselves debating with the senior noncommissioned officers who have been with the ship for years and know what works. The collision of fresh, sometimes naive approaches with a conservative institutional memory produces a creative tension that keeps safety and reliability from degenerating into a mechanical following of the rules.

The Navy has managed to balance the lessons of the past with an openness to change and create an organization that has the stability and predictability of a tightly run hierarchy

PHOTO: GEORGE HALL



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sort of high-reliability organization, the researchers tracked its success to a similar set of principles.

The Diablo Canyon nuclear power plant, operated by Pacific Gas & Electric, lies just west of San Luis Obispo, Calif., on the Pacific coast. Although its construction was dogged by controversy and ended up taking 17 years and costing $5.8 billion, the plant has by all accounts proved to be one of the country's best run and safest since it opened in 1985.

Like the aircraft carriers, Diablo Canyon appears at first to be a rigidly run hierarchy, with a formal chain of command leading up to a plant manager who is also a vice president of Pacific Gas & Electric. And it has a thick stack—a tower, really—of regulations telling employees how to do their jobs. This is how the regulators want it. Since Three Mile Island, the Nuclear Regulatory Commission has tried to ensure safety by insisting that nuclear plants follow an even more detailed set of rules. Plants are rated according to how many times they violate the regulations, and a pattern of violations will lead to closer supervision by the NRC and fines that, in serious cases, can run into hundreds of thousands of dollars.

But Paul Schulman, a political scientist at Mills College in Oakland who has collaborated with La Porte, Roberts, and Rochlin, has found that Diablo Canyon has another side—a more active, probing, learning side. Despite the hierarchy and the regulations, the organization is constantly changing, questioning accepted practice and looking for ways to do things better. It is not the same sort of change found on aircraft carriers, where the steady turnover of personnel creates a cycle of learning the same things over and over again plus a gradual improvement of technique. Diablo Canyon maintains a relatively stable group of employees who know their jobs well. Nonetheless, the nuclear plant is as dynamic as the carrier.

The reason, Schulman says, is that the plant has cultivated an institutional culture rooted in the conviction that nuclear plants will always surprise you. The result is two sets of decision-making procedures at the plant. The first, and more visible, consists of well-established rules for what to do in a particular situation. Some are carried out by computer, others by people. In general, Schulman says, this set of rules is designed to guard against errors of omission—people not doing something that they should.

but that can be flexible when necessary. The result is an ability to operate near the edge, pushing both people and machines to their limits but remaining remarkably safe.

No Failure to Communicate

Of course, an aircraft carrier is a unique situation, and there is no reason to think that what works there would be effective in a commercial setting with civilian employees. But when the Berkeley project examined a completely different

But Diablo Canyon employees also work hard to avoid errors of commission—actions that have unexpected consequences. Because a nuclear plant is so complex, employees must constantly think about what they're doing to avoid causing the system to do something unexpected and possibly dangerous.

This means that although the plant is constantly adding to its standard procedures as people learn more about the right approaches and spot new ways that things might go wrong, no one believes the organization will ever be able to

write everything down in a book. Thus the plant management chooses employees partly on the basis of how well they will fit into such a flexible, learning-oriented culture. The least desirable employee, Schulman reports, is one who is too confident or stubborn.

This sort of continuous learning and improvement would not be possible if the Diablo Canyon organization were strictly hierarchical. Hierarchies may work for systems that are "decomposable"—that is, that can be broken into autonomous units—but a nuclear plant is, by its nature, tightly coupled. A modification to the steam generators can have implications for the reactor, or a change in maintenance procedures may affect how the system responds to the human operators. Because of this interdependence, the various departments in the plant must communicate and cooperate with one another directly, not through bureaucratic channels.

Constant Learning: The Blessings of Ambiguity

Members of the Berkeley project have studied not just aircraft carriers and nuclear power plants but also air traffic control systems and the operation of large electric power grids, and they detect a pattern.

A layered organizational structure, for instance, seems to be basic to the effectiveness of these institutions. Depending on the demands of the situation, people will organize themselves into different patterns. This is quite surprising to organizational theorists, who have generally believed that organizations assume only one structure. Some groups are bureaucratic and hierarchical, others professional and collegial, still others are emergency-response, but management theory has no place for an organization that switches among them according to the situation.

The realization that such organizations exist opens a whole new set of questions: How are such multi-layered organizations set up in the first place? And how do the members know when it's time to switch from one mode of behavior to another? But the discovery of these organizations may also have practical implications. Although La Porte cautions that his group's work is "descriptive, not prescriptive," the research may still offer some insights into avoiding accidents with other complex and hazardous technologies.

In particular, high-reliability organizations seem to provide a counterexample to Yale sociologist Charles Perrow's argument that some technologies, by their very nature, pose inherent contradictions for the organizations running them. Concerning technologies such as nuclear power and chemical plants, Perrow writes: "Because of the complexity, they are best decentralized; because of the tight coupling, they are best centralized. While some mix might be possible, and is sometimes tried (handle small duties on your own, but execute orders from on high for serious matters), this appears to be difficult for systems that are reasonably complex and tightly coupled, and perhaps impossible for those that are highly complex and tightly coupled." But if Diablo Canyon and the aircraft carriers are to be believed, such a feat is not impossible at all. Those organization show that operations can be both centralized and decentralized, hierarchical and collegial, rule-bound and learning-centered.

Besides the layered structure, high-reliability organizations emphasize constant communication far in excess of what would be thought useful in normal organizations. The purpose is simple: to avoid mistakes. On a flight deck, everyone announces what is going on as it happens to increase the likelihood that someone will notice—and react—if things start to go wrong. In an air traffic control center, although one operator is responsible for controlling and communicating with certain aircraft, he or she receives help from an assistant and, in times of peak load, one or two other controllers. The controllers constantly watch out for one another, looking for signs of trouble, trading advice, and offering suggestions for the best way to route traffic.

Poor communication and misunderstanding, often in the context of a strict chain of command, have played a prominent role in many technological disasters. The *Challenger* accident was one, with the levels of the space shuttle organization communicating mostly through formal channels, so that the concerns of engineers never reached top management. The 1982 crash of a Boeing 737 during takeoff from Washington National Airport, which killed 78 people, was another. The copilot had warned the captain of possible trouble several times—icy conditions were causing false readings on an engine-thrust gauge—but the copilot had not spoken forcefully enough, and the pilot ignored him. The plane crashed into a bridge on the Potomac River.

When a 747 flown by the Dutch airline KLM collided with a Pan Am 747 on a runway at Tenerife airport in the Canary Islands in 1977, killing 583 people, a post-crash investigation found that the young copilot thought that the senior pilot misunderstood the plane's position but assumed the pilot knew what he was doing and so clammed up. And the Bhopal accident, in which thousands of people died when an explosion at an insecticide plant released a cloud of deadly methyl isocyanate gas, would never have happened had there been communication between the plant operators, who began flushing out pipes with water, and the maintenance staff, which had not inserted a metal disk into the valve to keep water from coming into contact with the methyl isocyanate in another part of the plant.

Besides communication, high-reliability organizations also emphasize active learning: employees not only know why the procedures are written as they are but can challenge them and look for ways to make them better. The purpose behind this learning is not so much to improve safety—although this often happens—but to keep the organization from regressing. Once people begin doing everything by the book, operations quickly go downhill. Workers lose interest and become bored: they forget or never learn why the organization does things certain ways; and they begin to feel more like cogs in a machine than integral parts of a vibrant institution. Effective organizations need to find ways to keep their members fresh and focused on the job at hand.

Any organization that emphasizes constant learning will

PHOTO: GEORGE HALL

Crew members on a carrier act as a team, communicating constantly through telephones, radios, hand signals, and written details. The constant flow of information helps flag mistakes before they've caused any damage.

have to tolerate a certain amount of ambiguity, Schulman notes. There will always be times when people are unsure of the best approach or disagree even on what the important questions are. This may be healthy, Schulman says, but it can also be unsettling to managers and employees who think a well-functioning organization should always know what to do. He tells of a meeting with Diablo Canyon managers at which he described some of his findings. "What's wrong with us that we have so much ambiguity?" one manager asked. The manager had completely missed the point of Schulman's research. A little ambiguity was nothing to worry about. Instead, the plant's managers should be concerned if they ever thought they had all the answers.

Schulman offers one more observation about high-reliability organizations: they do not punish employees for making mistakes when trying to do the right thing. Punishment may work—or at least not be too damaging—in a bureaucratic organization where everyone goes by the book, but it discourages workers from learning any more than they absolutely have to, and it kills communication.

If an organization succeeds in managing a technology so that there are no accidents or threats to the public safety, it may face an insidious threat: call it the price of success. The natural response from the outside—whether upper management, regulators, or the public—is to begin to take that performance for granted. And as the possibility of an accident seems less and less real, the cost of eternal vigilance seems harder and harder to justify.

But organizational reliability, though expensive, is just as crucial to the safety of a technology as is the reliability of the equipment. If we are to keep our technological progress from backfiring, we must be as clever with our organizations as we are with our machines. ■

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THE GENE D

The physician who has written the book linking g of genetic research will affect our lives.

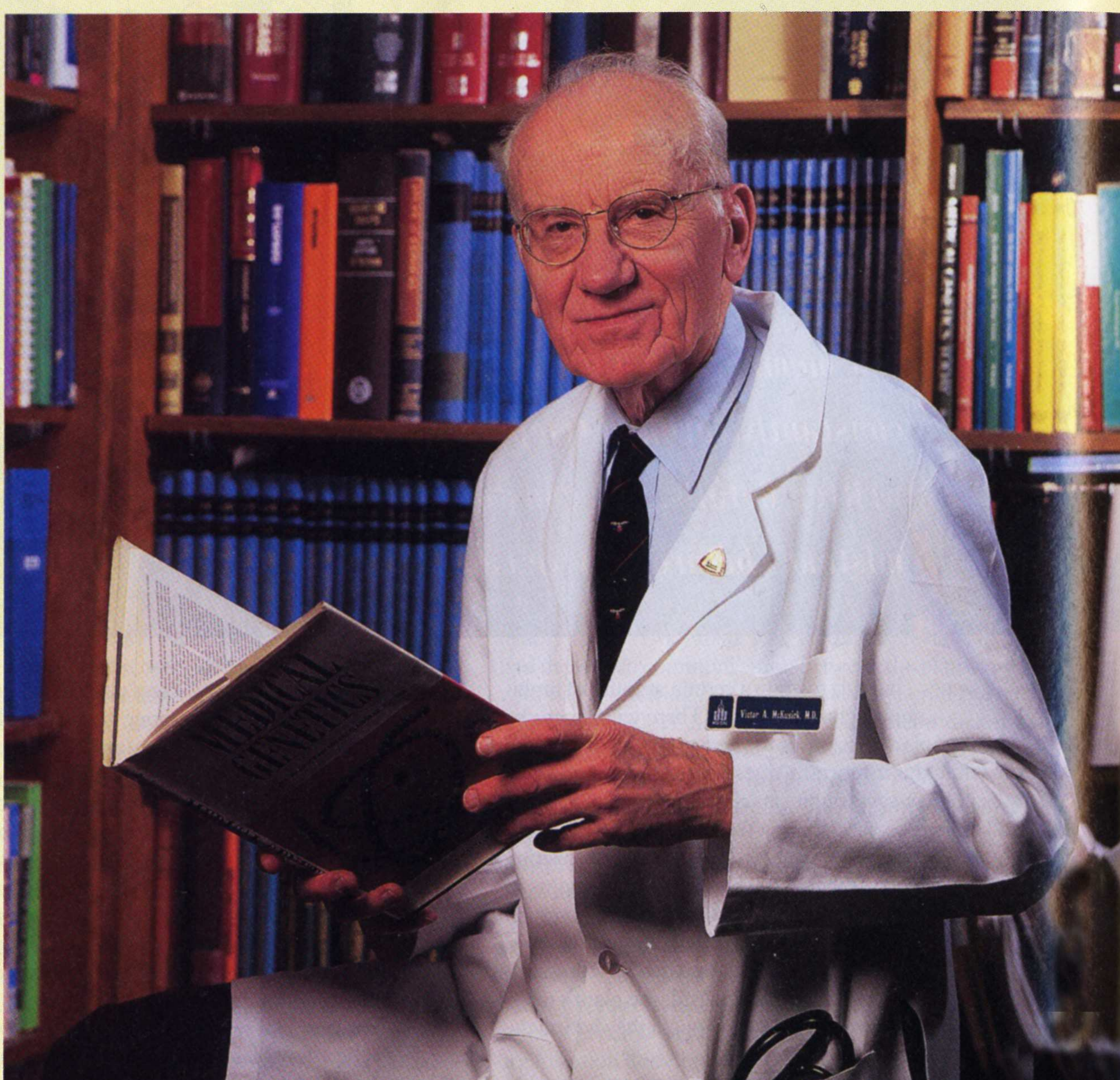


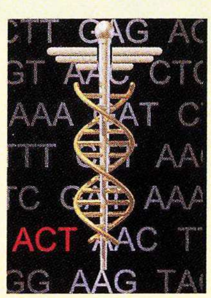
PHOTO ABOVE: CARL CARUSO; OPPOSITE: KENNETH EWARD/PHOTO RESEARCHERS

OCTOR IS IN

enes to disease explains how the next wave

The interviewer's embarrassment was rising by the moment. Despite having inserted fresh batteries and tested the tape recorder before the interview, she couldn't get the machine to work. Almost instantly Victor McKusick, at 75 the acknowledged founder of modern medical genetics, which focuses on the relationship between genes and human disease, dived below his desk. As the time he had carved from his packed schedule ticked away, he started crawling through a maze of computer cords to try connecting the recorder to an electric outlet.

McKusick's approach to the problem suggested his modus operandi: get involved. Indeed, he has thrown himself into four overlapping careers, beginning in cardiology, moving on to medical genetics, serving as physician-in-chief at Johns Hopkins Hospital, and finally helping to organize the international human genome project. Today McKusick spends most of his working hours updating *Mendelian Inheritance of Man*, a voluminous bible for researchers and doctors concerned with human genetic disorders. McKusick started compiling the text—which catalogs all human genetic sequences linked to particular functions, such as the gene associated with muscular dystrophy—in the early 1960s. At this point the compendium, also accessible online, contains some 9,000 entries. The 11 printed editions serve, as McKusick notes in the hard copy's 1994 edition, as an "archive of progress in human genetics in the last 30 years."



In the 1980s McKusick helped to bring about the Human Genome Project as a member of the National Academy

INTERVIEW WITH VICTOR McKUSICK

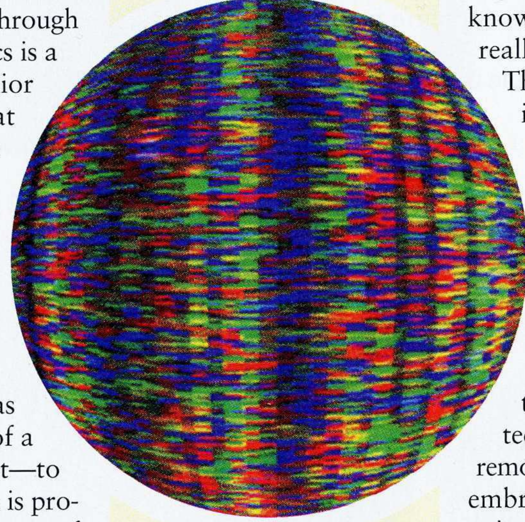
of Sciences (NAS) committee that evaluated the proposed project to determine the makeup of our entire code of DNA. During this period he also was a founder and the first president of the Human Genome Organization (HUGO), an international group involved in coordinating the effort. Through 1995 he contributed to a federally sponsored group grappling with the ethical, legal, and social implications of human-genome research. And he indirectly contributed to the infamous O.J. Simpson trial by chairing the NAS committee that evaluated the use of DNA technology in forensic science.

These are just a few of the tasks McKusick has handled over the years (he still sees patients weekly). And he has seemingly done nothing with ennui. "I've always enjoyed what I've done and approached it with great zest," he says; reporters who have seen him in action concur. In this spirit McKusick writes about human genetics in a chapter of *Emery and Rimoin's Principles and Practice of Medical Genetics*: the field "holds particular fascination because it involves the most fundamental and pervasive aspects of our own species." He continues, "To have combined with this intellectual and anthropocentric fascination the opportunity to contribute to human welfare and to be of service to families and individuals through medical genetics and clinical genetics is a privilege." *Technology Review* senior editor Laura van Dam recently sat down with a functioning tape recorder to ask McKusick where medical genetics is going today.

TR: What are the most important trends in research linking genes to human illness?

VMcK: There are three. First, focus has shifted from looking at the cause of a disorder—the precise genetic defect—to the mechanism by which the disease is produced. As Francesco Ramirez, professor of molecular biology at Mt. Sinai School of Medicine in New York, has explained, now that we increasingly know the why—which genes cause certain diseases—we must find out the how—how the genetic defects lead to particular problems.

Of great excitement is the burgeoning research on complex diseases—disorders such as hypertension and cancer that involve more than one gene.



TR: Why is it important to look at the mechanism by which the gene acts rather than just focusing on how to insert a correct copy of a gene?

VMcK: Despite all the hype about gene-replacement therapy, researchers are beginning to realize that it isn't going to happen soon enough for many medical conditions. Scientists have had a difficult time designing the vectors—the DNA couriers—that carry replacement genes to where they need to go, and producing genes that both persist and function at a high enough level.

If you know the steps that connect an abnormal gene to a disorder, by contrast, then you can often intervene along the way with appropriate drugs and essentially cure the condition.

TR: Why are researchers only now starting to look at the path between genes and disease?

VMcK: Some researchers have always focused on that, but interest is growing because of the rapidly advancing state of the human genome project, which participants hope will be completed by 2005. The public may have the impression that when the genome is completely sequenced—when we have determined the makeup of all of our DNA—we'll know the whole story. But that point will really just mark the end of the beginning. Think of the work entailed in determining the function of the 80,000 or so genes in that structure—research that will suggest how altered genes lead to diseases.

TR: How do scientists figure out how genes work?

VMcK: One of the main methods investigators are exploiting is knock-out technology. In this technique, scientists remove a gene from, say, a very early mouse embryo and then see what happens to the animal as it grows. If, say, the mouse develops a disease, the indication is that the gene is related to the condition. The technology is rather crude, however. For instance, if the gene is essential to its early development, the mouse may not make it to birth.

A newer, more delicate technique is known as knock-in technology. Researchers

SEQUENCED DNA IMAGE: WHITEHEAD INSTITUTE

can exchange a gene in an embryonic mouse with a corresponding gene from another species, such as a human. Doing so enables investigators to create particular mutations—one can, for example, put in the mutated hemoglobin gene that causes sickle-cell anemia. Then they can use the transgenic mice to figure out appropriate therapy for people. Investigators are now testing new drug treatments for sickle-cell anemia in such mice—a big advance since in the past humans were the only species that could be studied; no other animals naturally get the disease.

TR: What are the two other critical trends in medical genetics?

VMcK: The second area of great excitement is the burgeoning research on complex diseases—disorders involving more than one gene. Until recently we have largely studied single-gene disorders. Most of those are pretty rare, although there are plenty of them and for the people suffering from them they are very important. Diseases such as hypertension, cancer, asthma, and major mental illnesses involve a combination of genes, and that's what researchers are starting to try to understand.

TR: How do multiple genes cause a single disease?

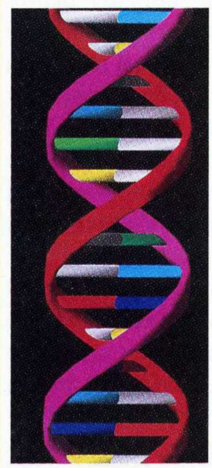
VMcK: Each of these genes tends to be polymorphic—it occurs in a number of forms—so that throughout a population of individuals the gene produces a varying amount of a certain protein such as an enzyme. If only one of the genes produces a somewhat low amount of protein, that may not affect an individual significantly. But if, say, three such genes do, the combination might make an individual susceptible to diabetes, cancer, or high-blood pressure. If environmental factors kick in—say, someone predisposed to heart disease doesn't exercise or eat properly—the person will end up with the disorder.

TR: Given that more than one gene has to be polymorphic to produce such conditions, I would think they'd be more uncommon than single-gene disorders. Why isn't that true?

VMcK: Think about a disease marked by too small a production of several enzymes. Let's say that 20 percent of a population has the form

I Am a Clone

WHEN PEOPLE ASK ME about my attitude toward cloning humans, I point out that the idea is not so novel. In fact, I am a clone; a single embryo produced both me and my identical twin Vincent (who has differed enough from me to have served as chief justice of the state of Maine's Supreme Judicial Court, and to have a master's degree in electrical engineering from MIT).



A question surrounding experimental human cloning is whether it really could be done.

In fact, humans cannot be perfectly cloned. If, for instance, a researcher decided to clone Albert Einstein, any such embryo would end up in a womb that would differ from the chemical environment of Einstein's mother. That environment would influence the offspring. Other differences would also arise during development. For instance, the ridges in the fingerprints of identical twins are not the same, owing to chance differences during that period. The same thing happens in the brain: as neurons migrate to make connections with other neurons, by chance they may take a left instead of a right at a fork, or vice versa. Human fetuses have many opportunities for such chance occurrences, since they remain in the womb a relatively long time.

And of course, the experiences that the Einstein clone encountered during the developmental years outside the womb would be quite different from those that Albert encountered. Again, this is not a short period: our physical maturation takes some 15 years or so.

In the end, we might even have a version of Einstein who would be nice to his wife. ■

—VICTOR MCKUSICK

IMAGE: MEHAU KULYK/PHOTO RESEARCHERS

of gene *a* that produces little of enzyme *a*, and 20 percent of that group has the form of gene *b* that produces little of enzyme *b*, and 20 percent of that group has a third gene that produces little of a corresponding enzyme. Multiply these percentages together and the result is 0.8 percent of the population—making the resulting disorder not terribly rare.

Single-gene disorders, on the other hand, tend to be so disastrous that the individual often dies before he or she can reproduce and pass the abnormal gene to a new generation. Single-gene disorders often arise through new mutations, which are rare events.

TR: How do scientists uncover all the genes involved in complex diseases, let alone determine the role of each gene?

VMcK: Investigators still have to find each gene one at a time, using the same process they employ for a single-gene disorder. But mathematicians and computer scientists have now devised methods for determining whether additional genes beyond those already identified are likely to be related to a complex-gene disorder. For example, Neil Risch, a distinguished biostatistician and professor of genetics at Stanford University, has proposed several approaches.

One entails working with genetic "markers"—known bits of DNA whose location on the genome has already been found. Risch has extended a long-understood notion: that if the same marker is found in many affected individuals, researchers can deduce that a gene that plays a role in the disease lies near the marker. Risch has determined that the frequency with which pairs of siblings with the same complex-gene disease have the same marker indicates how much of a role the nearby gene plays in the disease. The statistical findings tell investigators whether they have to search for other genes elsewhere. The technique is a little mind-boggling to someone who's not a biostatistician but it works.

As you can see, medical genetics relies on contributions from many fields, and it especially benefits from people who combine disciplines, for instance, those who keep one foot in computer science and the other foot in biology.

TR: And the third trend?

VMcK: The exciting effort to compare the genomes, or entire genetic complexes, of different species. Right now researchers are determining the genetic makeup of the genomes of the mouse, the fruit fly, a very simple roundworm called *Caenorhabditis elegans*, and a variety of bacteria. Several bacteria have already been completely sequenced, as has the yeast, a relatively advanced organism in that each yeast cell has a true nucleus. Because computer databases now contain genome information of various species, including the functions of identified genes, scientists can compare a particular human DNA sequence with similar sequences of other creatures. Researchers do this when they think they have found, for instance, a human DNA sequence with the characteristics of a gene, but don't have the foggiest idea about its nature. Using the databases, they can see if the human sequence closely resembles, say, a yeast gene with a known function.

TR: Why would our genes function like those in yeast cells?

VMcK: Humans obviously need many more genes than yeast—probably at least 12 times as many—but the fundamental program for cells is the same in both species. Consider, for example, what happens in a form of colon cancer known as hereditary nonpolyposis colon cancer (HNPCC). Investigators have figured out that this disease occurs because of defects in a class of genes called mismatch-repair genes. Those genes normally survey the genome and repair bits of DNA upon finding so-called mismatches between the two sides of the coiling DNA ladder. But a mutation in the mismatch-repair genes themselves can cause that check-and-balance system to go awry. When the resulting unrepaired mismatch is in a gene that normally suppresses tumors, such as of the colon, the result is the development of a cancerous tumor. For quite some time researchers knew only that mismatch-repair genes existed in bacteria and yeast. Then Bert Vogelstein, a professor of oncology at Johns Hopkins University School of Medicine, used a database to check a genetic sequence he had isolated from people with HNPCC against sequences of other species. He found

that the sequence he had isolated was a mismatch-repair gene, and went on to show that mutations in this and related genes could lead to HNPCC.

TR: Given all these new directions, geneticists would seem to have their hands full for quite some time.

VMcK: Oh, but there's more. Once the human genome project nears completion, we will have to face the fact that we do not know the distribution of various forms of genes around the world. That's important for determining what diseases, both infectious and degenerative, particular populations are prone to. Experts have therefore been discussing the idea of a human genome diversity project, which would look at gene variability.

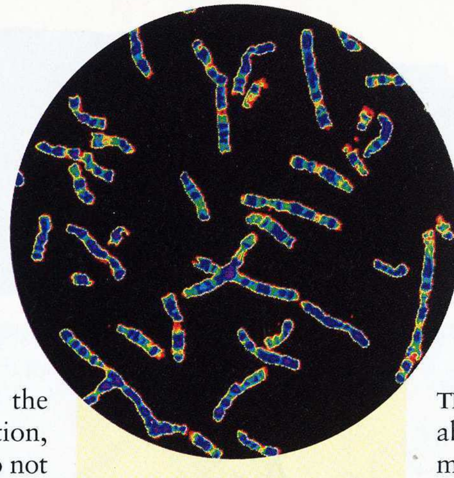
Some human-rights groups have reacted to the idea with alarm, because early advocates emphasized the notion of sampling the DNA of small, isolated populations in the Amazon and other out-of-the-way parts of the world before the groups disappear. Advocates for these groups worried that the populations would be exploited or stigmatized by the studies.

But the scientists promoting the human genome diversity project have started to recognize that they should instead focus on the rest of us. After all, the main pay dirt won't be found by studying small populations but by understanding the larger groups around the globe. That information can help researchers to determine future health prospects of large populations—groups with millions of members.

TR: Don't researchers already have a sense of how different diseases, such as stomach cancer, vary across the globe?

VMcK: To some extent, yes. For instance, we have a good deal of information based on studies from blood. But to get to the roots of disorders we need to examine the genes. After all, the variation of genes is related to the frequency of complex traits. Different populations can have different variations of those polymorphic genes I mentioned before—the ones that can have multiple forms—with the result being varying frequencies of specific complex disorders.

Of course, as I suggested before, environmental conditions also play a role in disease distribution. Diabetes is a good example. One of its two main forms, which usually occurs in people once they are adult, is often related to obesity. Increasingly sedentary populations are more apt to experience this kind of diabetes.



To figure out the function of a human DNA sequence, researchers can compare it with similar sequences whose functions are known in other creatures.

TR: As suggested by some groups' concerns about the human genome diversity project, much of the work to tease apart the human genome is raising significant ethical issues. What systems does society need to develop to address the dilemmas?

VMcK: This may sound simple, but airing ethical concerns, such as about the possible misuse of genetic information in connection with insurance and employment, is half the battle. Then, in part, groups such as—get ready for a mouthful—the Joint National Institutes of Health/Department of Energy Committee to Evaluate the Ethical, Legal, and Social Implications of the Human Genome Project (it's commonly called ELSI) can study the issues and make recommendations to the federal agencies funding genome research.

Moreover, sometimes the examination of ethical concerns by groups such as ELSI or the American Society of Human Genetics may influence governmental regulations. For instance, I suspect that as testing for genes that predispose people to breast or colon cancer becomes possible, the U.S. Food and Drug Administration will have to ensure the safety and adequacy of the kits produced for genetic tests, the accuracy of the resulting analyses in clinical laboratories, and the adequacy of genetic counseling related to the testing. The FDA is the logical overseer, since it regulates medical products. By, say, publicizing their discussions, outside organizations such as ELSI may help spur regulations concerning FDA involvement.

But the problems also go further to include the way the results are presented and the availability of follow-up counseling. A health-care provider could inform a woman that she does not have a gene predisposing her to breast cancer. In turn, she could adopt a laissez-faire attitude toward self-checks. Years later she might still end up with breast cancer, since the genes now

PHOTO OF CHROMOSOMES SHOWING DIFFERENT DNA SECTIONS: CUSTOM MEDICAL STOCK

associated with breast cancer account for a minority of the cases of the disease, and the tumor could have developed to a lethal stage. Preventing such situations requires appropriate education.

TR: Would that be accomplished by training more genetic counselors rather than relying on doctors who may not be familiar with the nuances involved in discussions concerning genetic risks?

VMcK: The savvy of all health-care professionals regarding ethical issues of genetics must rise. The situations are going to become increasingly commonplace. Every primary health-care provider must be prepared to provide counseling because, realistically, the number of genetic counselors will never be large enough to do the job. Genetic counselors will act as the specialists and teachers of other medical workers.

What's needed is a range of courses for everyone, from kids in high school to professionals. For instance, the annual "short course" in genetics I helped found in 1960 at the Jackson Laboratory in Bar Harbor, Maine, has helped educate several thousand medical researchers, doctors, and journalists—people who end up broadcasting what they learn to others—about the latest studies in genetics concerning mammals. Consideration of ethical issues is part and parcel of the program.

You know, when the course started, the status of genetics education in medical schools was woefully poor. I think that the course has had a major impact in changing that by educating medical instructors—"teaching the teachers." And efforts to educate the media are paying off in the kinds of discussions of ethical issues we regularly see in the press these days.

TR: Would you go as far as to suggest that all medical schools be required to offer a certain percentage of genetics-counseling courses? Should undergraduate schools and, say, high schools have to teach certain topics in genetics?

VMcK: "Require" is a bad word in terms of education, both because it's hard to do and it's incompatible with the American way of thinking. But even without requirements, the teaching of genetics at the levels you mention is improving all the time. Some of today's top geneticists, such as Leroy Hood, the founding chair of the Department of Molecular Biotechnology at the University of Washington, recognize the importance of teaching younger people about genetics and have begun to help public schools develop appropriate courses.

TR: Some observers worry that genetics may actually receive too much emphasis today—that laypeople and scientists alike could end up lacking training in other biological disciplines such as ecology that focus on whole organisms and also have broad social implications.

VMcK: Well, genetics isn't the whole story, but work such as sequencing genomes will lead us back to other critical fields. Consider taxonomy, the classification of organisms, which is a discipline important in ecology, since ecologists must be able to differentiate among many species. The database research I referred to is giving taxonomy a new life. For example, from genome-sequencing work scientists discovered that a form of life known as archeobacteria, a group of single-celled organisms that survive in harsh environments such as oceanic thermal vents, represent an entirely new kingdom of life. Geneticists determined that the genetic code for archeobacteria has key differences from all other bacteria, as well as other organisms. And studies of genome variation among populations within single species are really a form of ecological research, since part of that discipline is concerned with populations.

Moreover, the "big-picture" approach we're taking with the human genome project will likely extend to most other kinds of biological research in the future. By the way, we should remember that genetics is just a part of the picture that in one way or another we need to understand fully, for the world's betterment. In this era of growing scientific sophistication and ethical dilemmas, people need to look through a variety of lenses to understand what's happening. ■

As our genetic knowledge grows, every primary health-care provider must be prepared to provide genetic counseling.

PHOTO OF SUCCESSIVE EDITIONS OF *MENDELIAN INHERITANCE OF MAN*: JOHNS HOPKINS MEDICAL SCHOOL

Without a Car in the World

Trips take longer, and you have to bum rides, but life is sweeter when you're not tied to a ton of rolling steel.

By Jane Holtz Kay

THE trumpet sounded from eighth row center at a Washington University lecture hall in St. Louis five years ago. It was early in my explorations for the book that would become *Asphalt Nation*, and I was happy preaching to the choir. Or, I should say, to fellow passengers; for the students at the architecture school were already on the same trip. They knew intuitively, if not literally, the design formulas that I recited from the podium—for example, that every motor vehicle required building an ancillary seven parking spaces to hold it at rest. They realized that big chunks—some 30 percent—of our cities were hard-topped in service to the car's voracious appetite. And they knew how that transformed the built environment into a grim "carchitecture."

The students absorbed my other arguments on the broader compass of America's

PHOTOS BY L. BARRY HETHERINGTON

At times, living car-free took some doing. I learned to carry two books at a time instead of four, and to allow extra time to get to the movies or visit my mother.

car costs: financial, social, and environmental. They comprehended the motor vehicle's economic toll—$6,000 a year in personal costs and another $4,000–$5,000 in "invisible" ones borne by the public. They were startled by the health and environmental hazards of driving, from the more than 120 fatal accidents a day to habitat destruction and global warming. They had experienced the inconveniences of congestion and playing chauffeur, of parking and driving for miles to get a quart of milk. The room darkened and they chuckled at the slides of cartoons and auto-mated mayhem.

Then the questions started pouring forth. Toward the end of the evening came the telling one: "Do you own a car?" And with it my confession: Yes, I did.

Of course I did. With my first child I had bought my first car. In fact, I had recently purchased a new one, my third Saab—the most "environmental" one, I supposed, but a car nonetheless.

With that question, I knew I had to sell my private chariot. I realized that to explore the options or preach the message of car-free living, it was incumbent on me to be carless or, in the vernacular of the activists, "de-vehicularized."

I knew, too, I would assuredly hear the question again from others, believers and skeptics alike. More important, I knew I had to learn the answer firsthand. If I couldn't function without a four-wheeled vehicle, I would have to alter my book's subtitle, *How the Automobile Took Over America and How We Can Take It Back*.

A month later, my car was on the block at the dealer. I was car-free with cash in hand. And damn the consequences.

So what were the consequences?

Since this is a truth walk, I will offer another confession. Much as the image of martyrdom appeals, shedding the car was no ordeal. From the beginning, I had scant trouble adjusting to my nonmotored life.

Jane Holtz Kay is architecture/planning critic for The Nation *and author of* Asphalt Nation: How the Automobile Took Over America and How We Can Take It Back *(Crown:April 1997).*

And as the months wore on the pluses far outweighed the minuses. For me, at least, it was easy to be car-free.

For one reason, I live in a dense, urban neighborhood of Boston. I work downtown. I walk. My office, my friends and family, my entertainment and medical care are reachable by mass transit or on foot. Messenger services are available, and taxis can often fill the breach. My grown daughters have moved away—one overseas, the other to transit-rich New York. The supermarket delivers; the fruits and vegetables I carry home belie the professionalism of my briefcase but fit snugly inside. And because Boston holds many people who walk or take public transportation, services have sprung up to cater to their needs. This isn't Manhattan, with its 24-hour everything, but it is a city. Its neighborhoods and shops ease a hassle-free, less car-dependent life.

At times, it took some doing, I'll concede, and some thinking. I switched tailors. I learned to carry two books or two grapefruits at a time instead of four, to allow extra time to get to the movies or visit my mother. I traded chores for occasional rides and, sometimes, made friends and enriched trips with shared driving. At times, I abandoned a venture to some more distant place or used phone or mail order. Was it a sacrifice to reorganize or reduce my movement? A bit. But it was pure pleasure to forgo trips to the repair shop or the tow lot, or expeditions to the mall encased in a ton of rolling steel. Overall, I simplified my life. I saved time.

One spring day early in my car-free life, a new friend took me on a ride to trace the geography of my childhood and child-rearing days in my home town of Brookline, Mass. In only 10 minutes, we traversed the arc of my life . . . by the courtyard apartment where I grew up in an intimate, sidewalk community . . . up a hill to the small house on a dead-end street where I raised my children . . . past the home of my high school days, paces from my classroom. In short order, we had swung by the library, the corner store, the town swimming pool, my sister's house.

You have lived your life in such a small space, my friend, a planner, said thoughtfully.

"Small," I mused. It had seemed universe enough. Not small at all to a child on foot. Not small to an adolescent or a young mother. Not in the detail, the change, the shifting drift of streets, the palette of tree and vegetation, the variety of architecture, the scale of windows, the ornament adorning facades. Each locale, each corner, each doorway had meaning and actuality. Each segment had a rich and diverse presence as I walked from store to school to playground. To me, the arc was large as life: it was built at a walker's pace, and paced it I had. Its mobility was the pedestrian's—shifting, evolving, engaging eye and mind.

How different from carbound America's hypermobility and its blur of passing faceless places. "Houston is the modern world par excellence," the architect Daniel Solomon writes in his book *ReBuilding*. "The young man who drove me to the airport says he lives 30 miles from school, a one-hour drive each way. His $2^{1}/_{2}$-year-old truck has 78,000 miles on it and he hasn't been anywhere. Fifty times the Odyssey, eight times the travels of Marco Polo, how many hundreds of times the walks of Leopold Bloom? And with what density of experience, what

learned in his 78,000-mile journey?"

Not long after my hometown tour, a young German intern in my office gave me a Netherlands Friends of the Earth study of the motorized planet: the environmentalists calculated that to apportion the mileage of drivers in the industrial nations across the global population would allow each planet member only 400 motorized miles a year. A mere 400 miles! The thought was staggering. "How could we move?" I asked a friend. She responded ruefully that her daughter wouldn't be able to live in California. On the other hand, her daughter would be within walking or biking range. My friend's options were at once contracted and enlarged. Mine had been, too.

Travails of Travel

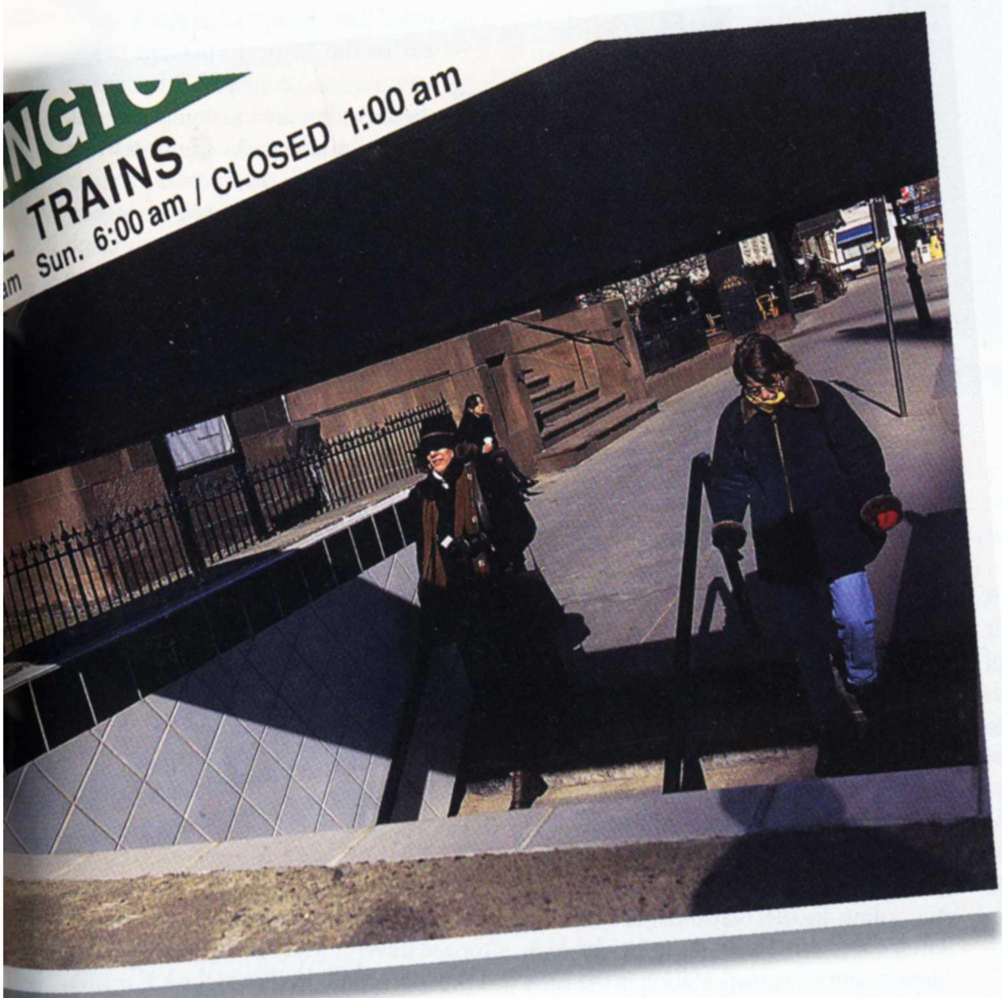
For all the conveniences of my home life, I soon found that moving around the wider, car-dependent country took commitment. When I ventured outside of my pedestrian-friendly city to give a speech to conservationists in Yonkers, N.Y.—some 200 miles south of Boston—I understood what deviation from the motorized norm meant.

My trip began with a rocky three-hour Amtrak ride to Stamford, Conn., followed by a 45-minute car ride with my host to the venue of the speech. There I met my daughter, who had come a dozen miles by mass transit from Manhattan. None of this was terribly arduous. The worst of it came on the return voyage.

My hosts had assured me that I could take public transportation back to Manhattan. One member of the audience offered to drive us to the nearby train station. Alas, as 11 p.m. approached, the station's bleak environs unnerved her. Instead she drove us to the "safe" bus stop on a lonely Yonkers arterial and dropped us off. Across the street from our perch, a pizza parlor glowed lifelessly in the dark. The sidewalks were mostly deserted. Cars passed; one slowed down ominously. Twenty anxious minutes later, we handed over the $7 fare for a 30-minute bus ride to New York City. Near midnight, we disembarked and caught a cab to my daughter's apartment.

From doorway to doorway, I had spent eight hours transporting myself.

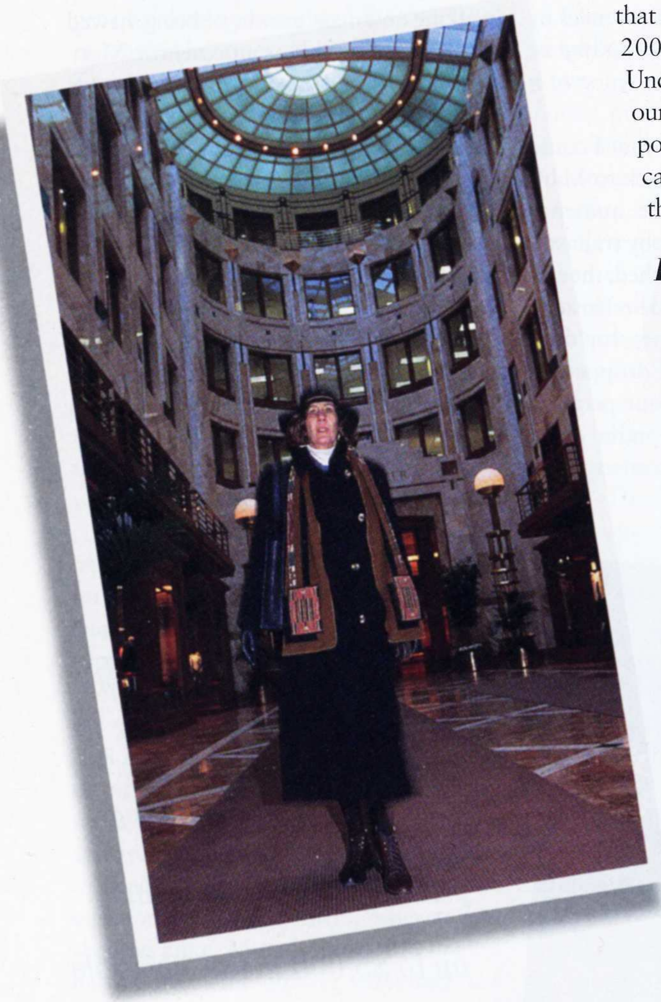
But whatever the wearisome aspects of walking and mass transit, of being viewed by skeptical friends as an eccentric Mary Poppins wafted by air, I had an easy answer to any predicament in my car-free life. In the back of my brain I carried the mantra of "$6,000," the amount I was saving each year by eliminating the expense of a car. And this figure, now $6,500, according to the Automobile Association of America, continues to rise. A distant doctor's appointment, a delivery charge for groceries or pizza, a cab here or there, paled in comparison to the cash



The author makes her way around Boston on foot and by public transportation, saving, she says, $6,000 a year in personal costs and up to $5,000 in the "invisible costs of automobile travel borne by the public."

benefit of almost \$20 a day I got from chucking my car. And, of course, I was practicing what I preached—and learning from the experiment.

Besides my own private gains, I was saving society almost that much in hidden costs, some in the form of pollution and environmental defilement;



some in public costs of motor registry services, land consumption, congestion, accidents, and on and on.

In the five years since I began work on *Asphalt Nation*, my car-free lifestyle has begun to look less oddball. Awareness of the automobile's social, economic, environmental, and architectural mischief has risen. Congestion, the most obvious symptom, grows as we travel ever more. So does the realization that our 5 percent of the planet's population owns close to half the world's cars, carrying with that ownership 50 percent of the blame for the automobile's destruction of habitat and contribution to global warming.

Many people want to escape from this ruinous path. Friends now envy my car-free condition, though they remain stubbornly dubious of their own capacity to emulate it. And indeed, after three-quarters of a century of catering to the car, their reluctance is understandable. How *do* people change? How can we reduce the average 11,000 miles per year that Americans drive each of their 200 million motor vehicles? Unquestionably, we can improve our carbound lot. Personally and politically, as I have learned, we can lessen our dependency on the automobile.

Roads to Freedom

What motivated me, and what does and could power others, was an awareness that I would no longer be forced to shuttle a minimum of 2,000 pounds (3,000-plus in a sports utility vehicle) to buy a Popsicle. Most drivers don't realize the hours spent behind the wheel on "shop 'n' drop." They think they use their car mainly to get to work and take vacations. Since two-thirds of all Americans live in metropolitan areas, and spend ten 40-hour weeks a year driving to work, that sounds reasonable. But the big picture is sobering. According to the Nationwide Personal Transportation Study done by the U.S. Department of Transportation in the early '90s, only 22 percent of our vehicle miles are used for commuting, and only 8 percent for vacation travel. The rest is errands, recreation, chauffeuring unlicensed family members. This realization alone should be enough to envision a better life without a motor vehicle.

A different set of wheels, the bicycle, can often take up the slack or eliminate one of the two or three cars in half our households. Some enthusiasts bike through truck-ridden, traffic-clogged mazes. Others see bicycling as promoting personal and planetary fitness as they perform, say, the 40-mile daily round-trip from Dover, Mass., to downtown Boston taken by Douglas Foy, head of the car-battling Conservation Law Foundation. Pleasure, politics, and the opportunity to save time motivate economist and transportation activist Charles Komanoff, who keeps five bicycles (for different weather and terrain) on hand for family odysseys from Manhattan.

But you don't have to be fanatical to join the 9 percent of the nation's households (largely poor) that don't own a car or the 30 or 40 percent of the population deprived of driving because they are too young, too old, or too disabled. As one pedestrian advocate tells me, most of the time when people dispense with their horseless carriage, it's through happenstance. The buggy gets too old to move another mile. The parking gets too tedious. Money is short. Sometimes

there's that other car in the garage. Michael Eberlein, coordinator of nonmotorized travel at Michigan's Department of Transportation in car-locked Lansing,

Staying car-free can mean coaxing a neighborhood shop to stock a missing item instead of driving to a megastore some distance away.

reduced his household to one car for financial reasons. "We were trying to find the extra $6,000 and couldn't," he says.

At first, the newly car-free gripe, and feel guilty about cadging rides. They sometimes learn to rent cars or take cabs, but otherwise frame their days on the human mobility of walking or bicycling. If they are lucky and live in a dense urban or old suburban area, they can take advantage of mass transit. The 80 percent of Manhattanites who do not drive endorse the saying that a car is "more trouble than it's worth." They walk or they ride the omnipresent rail and bus system allowed by places whose land patterns—densely settled, walkable—and commitment to public transportation sustain it. The backpack, the walker's constant companion, doesn't replace a "roomy interior," but it does help.

Opting for homes closer to a core—that is, accepting less house for the money—can save both time and transportation costs and offers the public life of parks, shops, and libraries. Living near a 24-hour store without a car is a money-saving proposition compared with driving to the superstore. Think again: does the Wal-Mart save you $6,000 a year? Then there are the extra parking spaces—the driveway and the garage—adding to the price of a home. Finally, driving (at $1 a mile, by some estimates) from ever-more-distant suburbs compounds the expense. In the end, the cost equation changes mindsets. In fact, in California, the Bank of America has lowered its mortgage rates for those who cut down on cars and live in non-sprawling communities. The trend to such "location-efficient" mortgages grows.

Jane Holtz Kay takes a shortcut through a building to save time during her daily commute. And she uses a briefcase to carry groceries as she makes her way around town.

Even car-bound consumers consigned to exurbia by work can find options for becoming less car-dependent. Businesses and institutions have begun to supply vehicles for parents to use in emergencies, provide chits for public transportation, organize car pools, and refund money to those who don't use their parking facilities. (The subsidy of free parking, like the subsidy of tax-supported highway infrastructure, tilts the balance to being car-dependent.) Paratransit—vans that loop through industrial zones or transport elderly and disabled people—can help. So can messengers and taxi systems; the tighter the land pattern, the greater the possibilities. Communities in Canada and Germany, as well as a few in the United States (including Eugene, Ore., and Boston), have instituted the car-sharing system: pay a fee and you have access to an automobile in a nearby parking lot. Just make a reservation, retrieve a key from a safe-deposit box, take a ride, and return the car.

Work options like telecommuting also stand high on some lists of solutions for lessening autodependency. Telecenters, urban "villages" where telecommuters share facilities and space near their homes, have opened nationwide.

The Personal Becomes Political

Yet futurists who project declining automobile travel as a result of telecommuting fail to reckon how small a number of telecommuters now exists (3 percent of the population), how small a percentage of miles is racked up by the commute, and how large a percentage is needed for errands in sprawling suburbs. The stay-at-homes still pass their days performing the personal trips that run annual mileage into five digits. Only if we solve the land-use issue—designing and preserving compact neighborhoods—can we make telecommuting really count.

Some car-free citizens have worked to such an end by trying to make their communities more walkable, in the process turning the personal into the political. For Chris Bradshaw, president of OttaWalk, a pedestrian advocacy group in Ottawa, staying car-free means fighting to preserve the community center or the blockfronts of small stores, and battling for a public "bare-pavement" policy to keep sidewalks free of snow. Such services and institutions make "trip-chaining"—the traffic engineer's word for performing serial errands—feasible on foot. To Bradshaw, too, staying car-free means coaxing a neighborhood shop to stock a missing item instead of driving to a Big Box store on the periphery.

For others, enhancing a car-free existence may mean stopping a road widening or extension that would bring traffic and threaten the pedestrian. Simple tactics such as widening sidewalks, building speed bumps, and planting trees to slow motorists can reduce the danger to walkers. Providing a safe route for a youngster to walk to school can eliminate two car trips per family per day. Approaching school committees or politicians raises the likelihood of success. Again, the personal becomes political when those who value walkable and bikable neighborhoods participate in zoning decisions to allow mixed commercial and residential development; when they fight to retain or add a streetcar route; when they lobby for more and better buses.

Efforts like these are multiplying as car-free advocacy groups grow in number and solidarity. The months-old WalkAmerica alliance already embraces more than 10 organizations. Advocates for greenways and bike routes, such as Transportation Alternatives, ally with environmental asso-

ciations such as the 1000 Friends of Oregon, the Environmental Defense Fund, or the Sierra Club. Across the political spectrum, trolley and train fans are uniting with opponents of highway boondoggles. Many activists are engaged in the fight to retain the nation's six-year-old Intermodal Surface Transportation Efficiency Act (ISTEA). The act, which directs 50 percent of federal transportation funds to nonhighway uses, comes up for renewal this fall.

Perhaps the broadest front on which to combat car dependency is economic policy. Automobile travel is heavily subsidized by local governments' underwriting of streets and roads, federal funding of oil wars (Desert Storm), and the hidden costs of the car-generated infrastructure that breeds sprawl. Hence there are many opportunities to curtail car use through the cash register. Our artificially low gas price of $1.25 or so is a quarter of Japan's or Europe's $4 to $5, which includes taxes to cover social and environmental costs. By paying the true cost of petroleum, other countries spend half the 20 percent of GDP that Americans spend on the private car (according to the Institute for Transportation and Development Policy in New York City) and can thus afford decent public transportation.

Stop subsidizing cars, and solo driving will go down while carpooling, cycling, and mass transit will rise, enhancing the car-free life. We can pay at the pump or pay in excise taxes or registration fees. Congestion pricing—charging more on roads and bridges during peak periods, as is done in Norway and Singapore—works well. So would a carbon, horsepower, or gas-guzzling tax: a nickel-a-mile surcharge would cut car travel (and hence automotive smog) 10 percent while reducing congestion 30 percent, according to research by economist Komanoff.

These are the choices our society must make collectively. If our culture rejects automobility, or hypermobility, as its Manifest Destiny, the car will be a servant, not a master. We have alternatives to a car-bound existence. People can live in places not encrusted with asphalt, improve their daily existence, establish a stronger sense of community, and know that they are advancing global well-being. For me, the long journey began with the footsteps toward a car-free life.■

Subsumed by Science?

The notion that technology is a mere subset of science pervades the media and our culture.

SAMUEL C. FLORMAN

"TECHNOLOGY Is to Science as Female Is to Male."

This title caught my eye as I leafed through a recent issue of *Technology & Culture*, the journal of the Society for the History of Technology. Ruth Schwartz Cowan had chosen the theme for her presidential address—partly in jest but mostly in earnest—and if her goal was to startle and attract attention, in my case she certainly succeeded.

Parts of the speech I read with cautious interest. I stress the word cautious, because when it comes to the subtleties of feminist theory, I am not totally at ease. But what I understood to be the main point of the essay struck me with great force. This is the "subsumption thesis," the idea that the most significant aspects of technology have been subsumed under the discipline of science. It follows that if science includes technology (as "man" is sometimes said to include "woman"), it is, by implication, a larger and more important topic.

One might say that this is merely a matter of semantics; but the fact is that words have tremendous force and implication. For example, some upholders of academic tradition scorn "women's studies" on the grounds that women are merely a subset of "mankind." A similar belittlement of engineering is implied each time the profession is called "applied science." The consequences in public image and, yes, in dollars—grants, salaries, and the like—are only too real.

To Cowan—who is a historian as well as a feminist—this concept is doubly irksome. In academe the study of technology was long viewed as merely a part of the history of science, and a not very important part at that. For decades, efforts to get leaders of the History of Science Society to pay more attention to the history of technology were unavailing. Rather than suffer continuing condescension, several technology specialists in 1957 decided to form a society of their own.

As it is with the historians, so it is with the practitioners. Engineers have long struggled to show that they constitute a learned profession, entitled to be treated as independent and equal partners with the community of scientists. The National Academy of Sciences (NAS) was established by congressional charter in 1863; the National Academy of Engineering (NAE) not until 1964. But even the creation of the NAE, important as that was, did not signal anything like true parity in authority and prestige.

Hardly a day goes by in which I am not reminded of the biases and misconceptions that prevail. National Public Radio airs an excellent weekly program devoted to science and engineering; they call it "Science Friday." I am a trustee of a wonderful museum of science and technology that bears what I consider an improperly abbreviated name: the New York Hall of Science. The *New York Times* publishes a special section every Tuesday covering many of the latest developments in science and technology. They call it "Science Times." This section recently carried an article on the "Shrinking Transistor" in which the word "scientist" appeared repeatedly, "engineer" not once. An accompanying photo of Jack Kilby, one of the most prominent engineers of our era, identifies him merely as "the first to carve multiple transistors onto a single wafer of semiconductive material." The first what?

Among engineers, such slights give rise to frustration verging on paranoia; but at least, having read Ruth Cowan's essay, I can now assess our problem more accurately than before. Engineers are not merely being ignored, insulted, or subjected to unfair prejudice. We are being subsumed.

The feminist analogy is helpful: Just as women should be considered equal partners with men in the human enterprise, engineering deserves respect and attention equal to that accorded science. But if carried too far, the analogy begins to confuse instead of clarify. Even the most biased historian cannot claim that technology began as part of science, as woman is sometimes conceived to have come from Adam's rib. Engineering was an established craft for centuries before the dawning of modern science. Even today, engineers agree that intuition, practical experience, and artistic sensibility are at least as important to their work as is the application of scientific theory.

As Cowan reaches the end of her essay, she suggests that we might solve our problem by concentrating on the ways in which science and technology are "similar, connected, united." But while this approach may help ensure equality of the sexes, it will not work as well for science and engineering, where the differences are at least as significant as the similarities. Einstein, with no practical end in view, sought to learn the ultimate nature of the far-flung universe; the Roeblings designed and built the Brooklyn Bridge to help people keep in closer touch—commercial as well as social—with their neighbors.

In his book *The End of Science,* John Horgan claims that while scientists loftily seek what is True, engineers merely seek what is Good. He means this as a put-down for engineering, but I take it as a compliment. I don't mind being challenged to defend what I do. I just don't want to be—what was that word again?—oh, yes—subsumed. ■

SAMUEL C. FLORMAN, a civil engineer, is the author of The Existential Pleasures of Engineering, *recently reissued in a new edition. His latest book is* The Introspective Engineer. *He can be reached at scf97@aol.com.*

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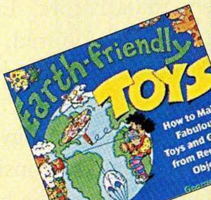

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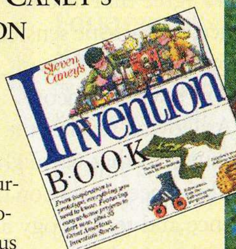

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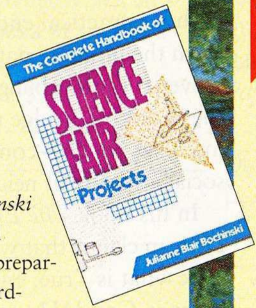

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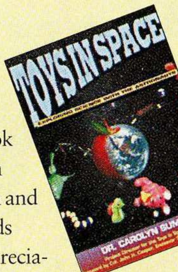

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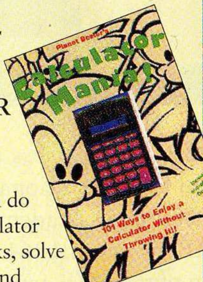

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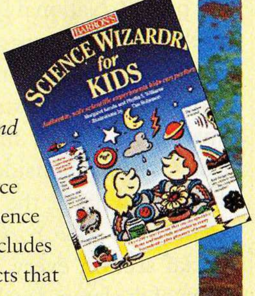

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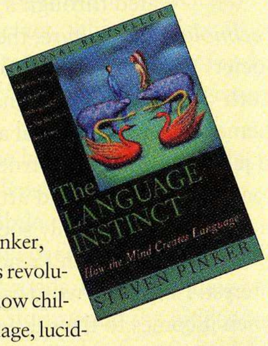

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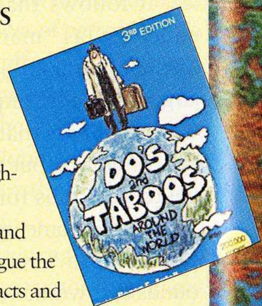

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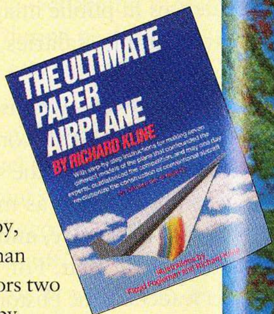

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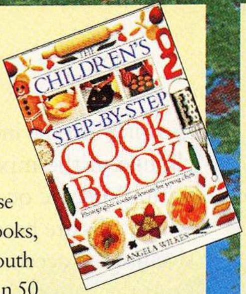

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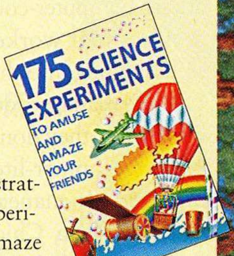

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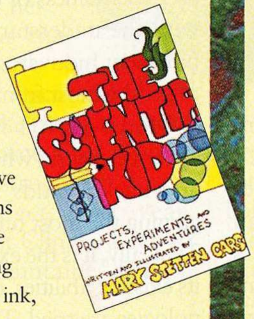

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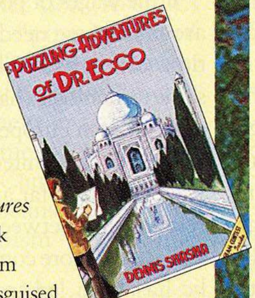

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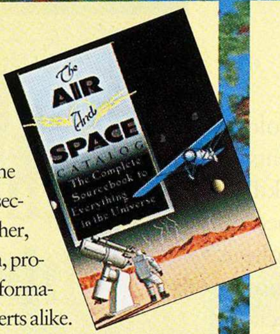

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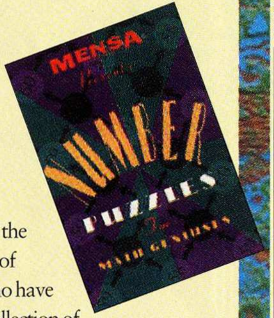

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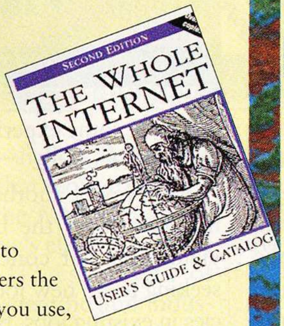

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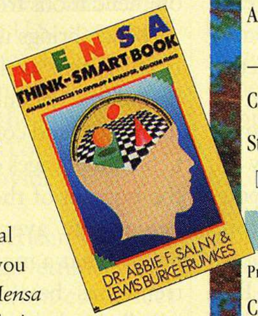

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Don't Blame Technology This Time

The alleged disappearance of low-skill job opportunities in the U.S. economy has been exaggerated.

BENNETT HARRISON

EVERYONE knows that technology and the changing requirements of employers are making unskilled workers an endangered species, right? That without at least some college education, workers in the U.S. economy on the eve of the millennium—especially persons of color—are doomed? It's a good story, and the storytellers are well meaning.

Only it's not quite so.

According to a recent report by the U.S. Bureau of Labor Statistics (BLS), relatively low-skilled positions accounted for most of the wage-and-salary employment created in the United States between 1983 and 1993. BLS defines such jobs as those that "can be learned quickly and that generally do not require post-secondary education." Moreover, projections based on BLS's *Occupational Outlook Handbook* conclude that for the period 1992–2005, two-thirds of the fastest-growing occupations will call for no more than a high-school degree.

None of this says that education is unimportant—that would be foolish. Nor is it inconsistent with the finding by Harvard University economist Ronald Ferguson that racial differences in math and language skills, as measured by standard written tests, correlate strongly with the gap between the earnings of black and white youth. What the findings do say is that the alleged disappearance of low-skilled job opportunities in America has been greatly exaggerated.

Not only exaggerated, but misunderstood. It turns out that what employers seem to want most from new workers is not academic credentials but rather evidence that the person has acquired basic skills and is able and willing to learn on the job. Recent studies support this point of view. Michigan State University economist Harry Holzer found from a survey of nearly 3,000 employers in four metropolitan areas (Los Angeles, Detroit, Boston, and Atlanta) that entry-level jobs are open to people with varied backgrounds. For hiring into jobs containing tasks that involve daily reading and writing, arithmetic, use of computers, or dealing with customers, Holzer found that companies typically want no more than a high-school diploma, some experience, or prior training and references.

A survey of another 3,000 companies nationwide by the U.S. Census Bureau yielded similar conclusions. Employers seeking to fill new jobs, and to fill vacancies in existing jobs, put relatively low priority on the candidates' years of schooling, test scores, or teacher recommendations. What matter far more are the applicant's attitude, communication skills, and recommendations from previous employers.

Which brings us to a companion myth. It is by now well known that earnings inequality widened considerably during the 1980s (and continues to do so). In particular, the wages of low-skilled workers at the bottom of the ladder fell drastically behind the average. Most economists believe that a major explanation for this trend has been a tendency for newly installed technology to require high-skilled workers to operate it. But new studies by economist David Howell and others paint a picture inconsistent with this theory. Between 1980 and 1990—the decade of growing income inequality—there was no change in the mix of skills to be found within specific occupations. The pace at which jobs are becoming more skill-intensive has not accelerated.

At the base of this flawed analysis is the perception of technology as primarily skill-*demanding* rather than as skill-*enabling*. The conventional wisdom assumes that a new technology-intensive task, such as navigating the World Wide Web or operating a computer-controlled printing press, requires that workers have the requisite skills coming into the job.

Some managers do impose such requirements. But they don't have to. I have seen barely computer-literate secretaries learn on the job to maneuver around the Internet. And at a Chicago-based company printing children's books in a spanking new plant on the Mexican border, I observed young men and women barely off the farm training—again, on the job—to operate state-of-the-art printing equipment. The user-friendliness of the software combined with the understandable fears of unemployment motivated the unskilled workers to get the most from the technology.

Moreover, it is impossible to know in advance exactly what sort of worker skills and backgrounds will be best suited to gaining the most out of a new technology. Typically, it is the existing work force, with its existing abilities, on whom the new technologies are tried. The most adaptive companies are those whose managers and workers learn the most from such trials.

If the wages of poorly educated workers are falling, we need to look for explanations other than technology. After all, the same technologies have penetrated factories and offices in Europe and Asia, yet nowhere outside of the United States have low-end wages fallen so far and so fast. Clearly, the relationship between technology and job skill is a lot more complicated than the public has been led to believe—and full of opportunities as well as pitfalls. ■

BENNETT HARRISON teaches urban policy and economics at the New School for Social Research in New York (benh@tiac.net). His latest book, Workforce Development Networks, *will be published later this year by Sage.*

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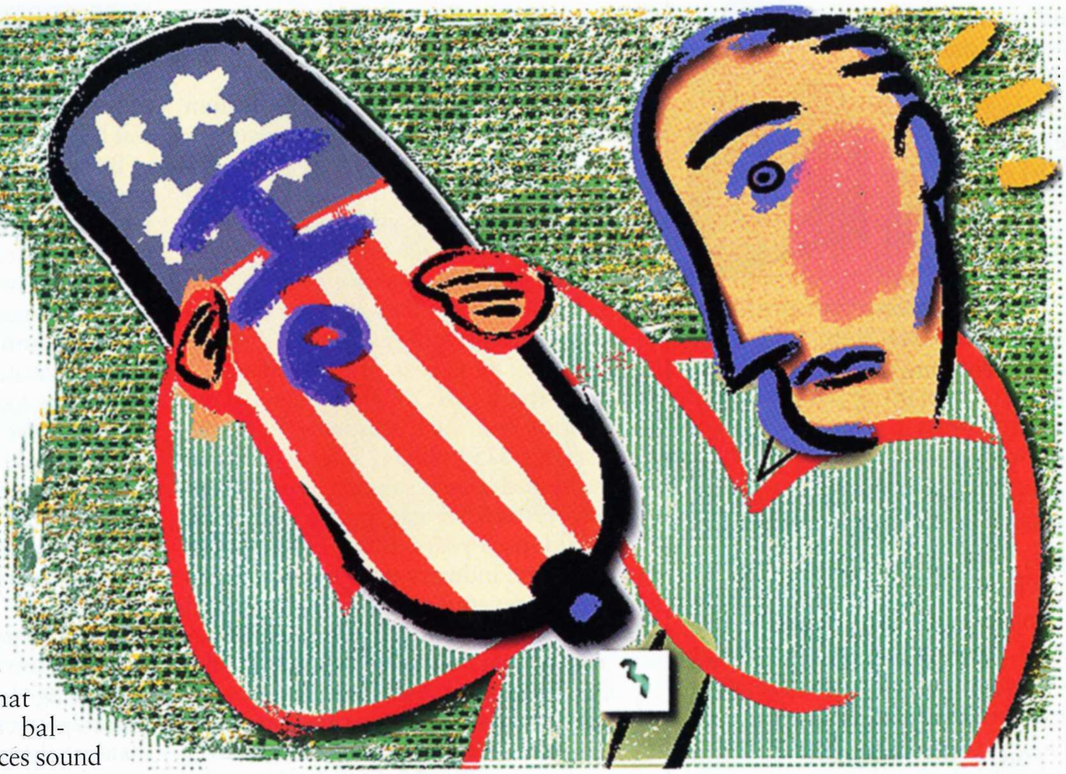
FORUM

BY CHRISTOPHER THOMAS FREEBURN

Save the Helium



A swing of the congressional budget ax has killed the strategic helium reserve, even though public and private research depends on steady supplies of the element.

To most people helium is the gas that makes children's balloons float and voices sound like Donald Duck. In the last two years, however, helium became a focal point in the messy political struggle to downsize the federal budget. Last year, Congress and President Clinton acted to sell off the federally maintained helium reserve.

Critics have ridiculed the helium reserve as a white elephant left over from the days of World War I dirigibles. Representative Christopher Cox (R-Calif.) labeled the reserve a "poster child of government waste." President Clinton originally called for the helium reserve program's improvement as part of his "reinventing government" proposals. Ultimately, however, Clinton sided with congressional Republicans, labeling the reserve "an anachronism" and calling for its elimination.

In the swirling winds of political rhetoric, however, the government may have acted precipitously. Helium has unique properties that make it irreplaceable for science and industry. As the only element that does not freeze solid—remaining liquid even at just a fraction of a degree above absolute zero (-460 degrees Fahrenheit)—helium is essential for a variety of uses that require extreme cold. According to the American Physical Society, the reserve's elimination will lead inevitably to U.S. shortages of helium and disrupt scientific and industrial research.

The United States is home to rich natural reserves of helium, mixed with methane in the gas fields of Texas and Wyoming. U.S. companies recover more than 3.3 billion cubic feet of helium every year. In 1996, the U.S. consumed 2.4 billion cubic feet of helium and exported another 970 million cubic feet of the gas. Because of the slim margin between production and consumption, a reserve is crucial to provide consistent supplies.

According to the American Geological Institute, the federal government uses approximately 300 million cubic feet (MCF) of helium a year on space, military, and civilian research. NASA, for example, has found helium essential for purging and pressurizing the fuel tanks of spacecraft because it is the only element that remains a gas at the extreme cold necessary to maintain the liquid hydrogen fuel used in many rockets and the space shuttle.

A host of industries have become similarly dependent on a consistent, expanding, supply of low-priced helium. Heavy users include superconductivity researchers, who use 172 MCF of helium a year. One of the major applications of superconductors—magnetic resonance imaging for medical diagnostics—consumes another 440 MCF. Gas-tungsten arc welding, taking advantage of helium's inert nature, employs the gas to protect metal from oxidation, creating demand for about another 460 MCF. Helium is also valuable for detecting leaks from even the most microscopic cracks and pores in sealed containers such as fuel tanks and the "clean environments" of electronics fabrication facilities. Other emerging technologies that depend on helium include fiber-optic production, which demands an ultra-pure inert atmosphere, and Josephson junctions—liquid helium-cooled

ILLUSTRATION: SUSAN LEVAN

superconducting microswitches that are faster and more energy efficient than today's semiconductors.

Congress created the strategic helium reserve in 1925 mainly to ensure a steady supply of helium for military applications such as dirigibles. In 1960 the program was expanded to include refining and storage facilities and a permanent stockpile. The reserve now holds 32 billion cubic feet of the gas in an abandoned natural gas cavern called the Cliffside Dome near Amarillo, Tex. To create the reserve, the Department of the Interior and the Treasury offered the reserve a $252 million loan to purchase the needed helium supplies, mostly from private natural gas refineries, to be repaid in 25 years. But sales of helium to private industry have not generated enough revenue to repay the loan and accumulated interest. The result is a $1.4 billion "debt" owed by the reserve to the U.S. Treasury.

Critics of the helium reserve have cited this debt as a measure of the reserve's inefficiency. But this is misleading. The so-called debt is an accounting formality, owed by one agency of the federal government to another; it could be written off without significant consequence to the federal budget, according to the General Accounting Office and the Department of the Interior's inspector general.

Nevertheless, the Helium Privatization Act of 1996, introduced by Rep. Cox last September, moved through Congress with speed rare for a measure killing a federal program, and President Clinton promptly signed it into law. The bill instructs the secretary of the interior to eliminate all federally operated helium refining activities and to dispose of all equipment and facilities. By January 1, 2005, the Department of the Interior is to begin selling all remaining helium reserves.

In a concession to scientists and advocates of the helium industry, the bill also requires the National Academy of Sciences to study the sales of the helium reserve to determine if the reserve's elimination will hurt U.S. industry. The Secretary of the Interior is also directed to monitor the sale of helium from the reserve to ensure that the sale of so much of the gas does not disrupt the commercial helium industry.

By eliminating the reserve, the federal government, which consumes nearly 75 percent of the gaseous helium market, has placed itself at the mercies of the market. Private markets often see periodic shortages and supply swings; without a guaranteed supply, NASA and other government agencies might find themselves forced to bid against private concerns for limited supplies, whose prices would be driven considerably higher in times of shortage. This rise in helium prices may wind up costing the government more in the long term than it would have to maintain the helium reserve.

It may be possible to reach a compromise position between those who favor abolishing the reserve and those who seek to protect it. Organizations such as the American Physical Society do not oppose privatizing the reserve per se, so long as it is not destroyed. If the federal government, burdened by budgetary problems and bureaucratic sprawl, is no longer willing to manage the reserve, it could be turned over to some form of private partnership involving helium suppliers organized to preserve and administer the stockpile.

The federal government could implement such a partnership easily enough by forgiving the helium reserve's artificial $1.4 billion debt and seeking the participation of private suppliers. Those suppliers have an interest in keeping the reserve—if only to prevent the market price of helium from plunging in the wake of a wholesale sell-off of the stockpile. Such a partnership would ensure the nation a steady supply of helium while still satisfying the desire of congressional budget hawks to shrink the federal government. ■

CHRISTOPHER THOMAS FREEBURN is a writer based in Tuckahoe, N.Y., who covers science, technology, and the environment.

BOOKS

Critiquing Online Communities

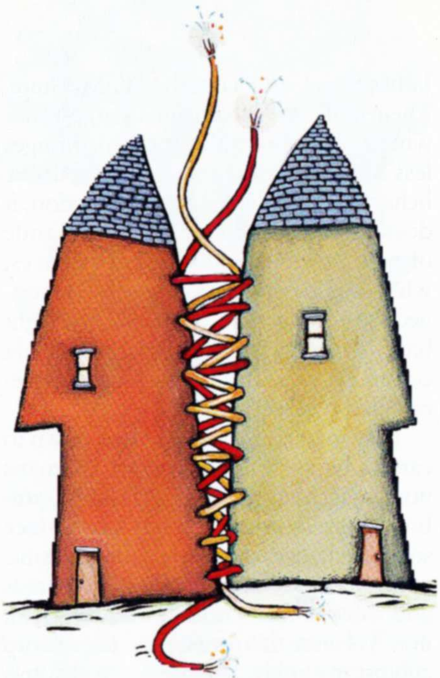
The Wired Neighborhood
by Stephen Doheny-Farina
Yale University Press, $25.00

BY NORMAN WEINSTEIN

EVER since science fiction writer William Gibson coined the term "cyberspace," computer users have struggled with the notion of what exactly that "space" means. For example, as I sit at a keyboard in Idaho preparing to send my review into this "cyberspace," I can visualize what states it might cross, but I know that it will not travel through pathways mimicking interstate highways or continental air routes. The e-mailed manuscript seems to inhabit such a non-specific, disembodied, and abstract space that I think of Gertrude Stein's description of Oakland, Calif.—"there is no there there."

That troubling uncertainty about the meaning of cyberspace inspired Stephen Doheny-Farina, professor of technical communications at Clarkson University, to write a curious book. The author's thesis, plain and simple, is that global computer networks are enhancing our isolation from one another, and that the growth of virtual communities is leading us away from the kind of neighborhood activism needed to restore decaying infrastructures in our real-life communities. He proposes trying to counter this tendency through net-bound neighborhood action forums. Defining himself in his preface as neither a "techno-utopian" nor a "neo-Luddite," he pledges to chart a middle way through computer network communications.

It seems like a promising stance. After all, many authors highly critical of the social consequences of communications technologies appear to suffer from ideological baggage. For example, consider James Brook and Ian A. Boal, editors of *Resisting the Virtual Life*, who see new technologies in light of their ability to maintain social injustices within capitalism. Other writers are prey to sloppy overgeneralizations, like Clifford Stoll, whose *Silicon Snake Oil* defines electronic communication as "illusionary contact." As for boosters of the new technologies, they are guilty of their own styles of too-loose or too-rigid thinking. Futurist George Gilder thinks computer technology will mystically contribute to the overthrow of matter, while cyber-philosopher and scientist Nicholas Negroponte would divide the world's population into those "wired" and those not as blessed.



But the difficulty is that while Doheny-Farina claims to neither valorize nor demonize technology, he very much personifies and scapegoats it. He writes of "powerful cultural trends" that are "seducing" us into "technological immersion." The "seduction" motif occurs throughout this book, as do other romantically charged terms. In his opening chapter he tells us that once we begin to "divorce ourselves" from "geographical place," we "further the dissolution of our physical communities."

In fact, the basic assumption that on-line communication means cutting ourselves off from our neighborhoods is itself worth noting. Proof? The author offers none. Instead, he constantly reasserts his monolithic opinion that the net "does not make the home into the center of our public and private lives but eliminates the center," and that as a result "all centers—work centers, school centers, and living centers—become less and less relevant." It is as if the act of turning on one's PC cancels out the freedom to explore all places other than those glowingly and symbolically present on the monitor. Indeed, for a writer who proposes on-line community activism as the chief worthy use of communications technologies, Doheny-Farina has a curiously passive view of human nature. People are depicted as helplessly drowning in waves of technological invention.

Building Up Expectations

Perhaps the most serious problem with *The Wired Neighborhood* lies in its failure to develop a clear and comprehensive way of talking about the qualities of computer-mediated communication and how they affect us. But this failure deserves to be shared with the scientific and business communities that reap the financial rewards of selling processes and products shrouded in mystification. The on-line industry does build up user expectations, no doubt quite unrealistically. A physician friend once told me he quickly tossed out one company's startup disc, which was packaged in an envelope enjoining him to "go on-line and change your life now!" "I don't have time to change my life now," he ruefully noted. Yet how many others would find such a repeated invitation tantalizing? Since his writing so closely resembles that of a disappointed lover, I suspect Doheney-Farina once was drawn in by such a utopian prospect.

We need to step back and take a look at the language we use to describe our experience with cyberspace. What does it mean to be "wired," to live in a "virtual" community, to be "net savvy"? "Science and technology multiply around us," writes science fiction author J.G. Bal-

ILLUSTRATIONS: ROBERT BRINKERHOFF

lard. "To an increasing extent they dictate the languages in which we speak and think. Either we use those languages, or we remain mute." That quote, marginalized in a field of neon-yellow ink in a recent issue of *Wired*, typifies the sort of statement that cries out for critical examination. Who says that we must use scientifically and technologically approved languages or become speechless? Why can't PC users invent their own languages, or subvert the existing ones?

The truth is that this might be happening already. *Wired* magazine regularly publishes a glossary of emerging computer jargon, for example. Doheny-Farina also would have done well to investigate some of the recent research into the differences between face-to-face and on-line communication, like the work of social psychologists Sara Kiesler, James Siegel, and Timothy W. McGuire. Their tentative conclusions suggest that while wired communication encourages less self-regulation and more impulsive behavior than face-to-face interaction, it does lead people to try out a multitude of novel problem-solving perspectives, which could contribute to a sense of connection among users. Such insights might have helped the author think about net communication from a less strictly place-centered perspective.

They might have brought him down to earth a bit as well. Are we poor humans now so incapable of distinguishing symbolic from flesh-and-blood, face-to-face social exchanges that we require academic authorities to remind us of the uniqueness and value of real-world intimacy? I think not. As I write this review, my dog rubs up against my ankle. She needs a walk, and the "virtual" neighborhood isn't where we will do that. The computer monitor is adjacent to my study window. I see my neighbors walking their own pets, or getting ready for the commute into work. The 15-inch monitor doesn't block my view of the neighborhood—it supplements it. However immersed I become in what I see on my monitor, the window and dog locate me in a non-virtual world.

More significantly, really knowing one's neighbors—whether literal neighbors or on-line neighbors—is arduous work. A better book would have developed a conceptual framework within which both face-to-face and computer-mediated relationship building could be critically explored. Such a book would have been broadly interdisciplinary, drawing upon various arts and sciences that concern themselves with communication. What can dramatic literature teach us about how various styles of self-expression convey rootedness or alienation? What can theology teach us about ways of communicating with invisible beings? How can social psychology, following the lead of Kiesler, Siegel, and McGuire, develop a framework for understanding the differences between wired and unplugged communication? There may be "no there there" in cyberspace, but many on-line communicators do report a sense of emotional and intellectual bonding. Whether that will translate into the hard work of strengthening our actual neighborhoods . . . who can tell? I do know that it is time to turn this computer monitor off, walk the dog, and greet the neighbor who I just glimpsed through my window.■

NORMAN WEINSTEIN is a poet and critic whose most recent book is A Night in Tunisia: Imaginings of Africa in Jazz *(Limelight Editions, 1992).*

BOOKS

INSIDE THE BOMB FACTORY

Nuclear Rites
by Hugh Gusterson
University of California Press, $39.95

BY PAUL ROGAT LOEB

WHAT is it like to design weapons of mass annihilation? How do the people who produce such weapons justify their work? MIT anthropology professor Hugh Gusterson spent two and a half years at the Lawrence Livermore Labs, where scientists have been creating atomic weapons since 1952, and his book *Nuclear Rites* addresses those questions. Gusterson began as a nuclear peace activist, then was struck by how much he personally liked a Livermore scientist he debated. *Nuclear Rites* works to view the researchers as complex human beings rather than as caricatured Dr. Strangeloves, and examines how they form their identities as bomb designers.

Central to Gusterson's task is a look at Livermore's ethos of secrecy. Security checks, which emphasize the scientists' membership in a rarefied community, buttress their pride in their skill, knowledge, and patriotism. But at the same

time, such measures frequently push them to monitor their actions and police themselves against suspect behavior, like attending the meetings of peace activists. Formal and informal rules also prevent Livermore scientists from discussing their work with outsiders, including their own spouses. One wife never found out about her husband's project until she sat in on his interview for the book.

Gusterson goes on to point out that the nuclear tests the Livermore scientists supervise are critical rites of passage, strengthening community ties. The act of surmounting the massive technical obstacles these tests present reinforces participants' shared assumption that atomic weapons, if handled competently, are controllable. And this sense of mastery carries over to the political and military context in which the bombs are to be used. For the scientists, in other words, nuclear tests supply a "symbolic simulation" of the "system of deterrence itself," Gusterson writes. In fact, many Livermore scientists regard their bombs as such a powerful deterrent that they believe they will never be used, and thus differentiate their work from the production of conventional military technologies like napalm. Some even marched in 1960s antiwar protests or opposed Reagan-Bush environmental policies.

Yet whatever their beliefs, Livermore scientists focus less on political matters than on the satisfaction of meeting technical challenges. Designing nuclear weapons piques their scientific curiosity. They have the privilege of working with highly intelligent colleagues in what one described as "the ultimate toy shop" of state-of-the-art equipment. They avoid having to genuflect to academic or corporate bureaucracies. And they channel their passion for invention into what Gusterson calls "a source of binding energy"—something capable of holding them together even when outsiders question their mission.

Other studies of atomic weapons facilities—including *New York Times* science writer William Broad's *Star Warriors*, novelist Grace Mojtabai's *Blessed Assurance*, and my own *Nuclear Culture*—have described a similar mix of political silence and technical passion, and a similar sense of a world apart. But Gusterson raises some new issues. Most significantly, he reports that most of the scientists he talked to mentioned the potential human impact of their bombs only in passing. Perhaps because they have concentrated so intensely on demanding and ever-changing technical specifications, they seem to have converted the bodies onto which their weapons might land into what he calls "a set of components that undergo mechanical interactions with blast waves and glass fragments."

Embracing Vulnerability

Gusterson maintains that such a sense of abstraction is key to enabling people to develop bombs. To illustrate his point, he contrasts the responses of three scientists who witnessed aboveground nuclear blasts. The first embraced his work with unalloyed enthusiasm and described the bomb's impact as "impressive" and "interesting . . . a very spectacular result." The second described the blast as "just stunning," but then acknowledged a "very heavy feeling," a physical sense of foreboding that brought forth continuing misgivings about his work. The third scientist, though he witnessed a smaller blast from just as far away, described crouching over, terrified, and feeling his heart beat as he urinated in his pants. Although this man could talk the technical talk as well as any of the others, he felt physically frail when faced with an actual nuclear explosion. That sensation eventually led him to stop working on such weapons.

What makes Gusterson's preoccupation with the scientists' detachment especially interesting is that it allows him to arrive at a new understanding of their opponents. If those who carry out the mission of labs such as Livermore need to repress a gut feeling of vulnerability, those who question that mission are more or less required to embrace it, in his view. Otherwise the lab's business becomes, to quote one scientist, "no stranger than making vacuum cleaners." As *Nuclear Rites* perceptively notes, doctors helped spearhead the Reagan-era nuclear peace movements not only because particular individuals, like Helen Caldicott, were charismatic, but also because they offered a countervailing expertise to that of the weapons strategists. They provided credible, specific details about the horror of potential cataclysm, and helped us imagine the physical impact of a typical bomb on actual human beings. They helped shift public discussion of the arms race from technical abstractions to the potential of global annihilation.

Unfortunately, Gusterson fails to acknowledge that the peace movement is built on more than personal fear. Activists I interviewed for my book *Hope in Hard Times* consistently stressed that terror of their own death by atomic fire was not driving them: they knew they'd die one way or another at some point. Rather, what stirred their hearts was the unprecedented threat to the world they expected to leave behind. Although Caldicott and others may have brought many to the movement by taking them into the eye of the nuclear hurricane, grassroots activists say they persisted because of their sense that they are responsible for something larger than themselves.

But probably the most serious shortcoming of *Nuclear Rites* is that Gusterson does not distinguish between respecting people's narratives and abdicating judgment on critical moral issues. He repeatedly undercuts his insights

CONTINUED FROM PAGE 8

with academic theories that suggest it's impossible to find clear right and wrong in the actions of either the weapons designers or their opponents, only "competing regimes of truth," as French philosopher Michel Foucault says. One moment Gusterson dissects the ways that Livermore's weapons designers silence any qualms in the face of their community's cultural pressures. The next he cites theorists like Jacques Derrida and Jean-Francois Lyotard, who resist the very idea that there could be an absolute definition of morality or truth. Or he quotes the notion of anthropologists Mary Douglas and Aaron Wildavsky that environmental activists respond less to real ecological threats than to socially conditioned trigger points based on their own background.

It's a strength of the book that Gusterson likes the weapons designers. Without his empathy for his subjects, he could hardly have understood them as well as he does. Still, the actions undertaken at Livermore and other institutions in America's atomic archipelago have had human consequences that go beyond ideology, conditioning, or cultural creation. Maybe the Livermore bomb designers are right, that America had—and has—no other course. Maybe they are wrong, as I strongly believe, and blinded by their investment in their work. But to imply that all we can do is observe how people create contending belief systems is simply to ignore the question.

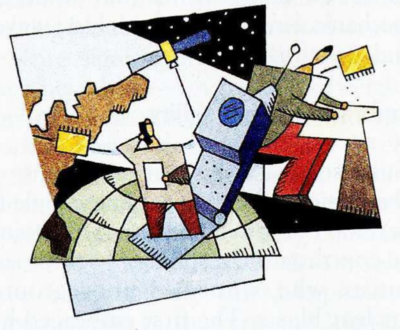
We indeed live in a time of competing ethical frameworks. Nevertheless, shared bases for discussion do exist—like the duty to avoid causing human pain and to alleviate that pain whenever possible. Such ethical touchstones don't furnish unequivocal prescriptions: Livermore's scientists would argue that their weapons, far from causing pain, actually prevent it by maintaining the stability of deterrence. But the theories Gusterson seems to favor too often enshrine the uncertainties and ambiguities of our time, so that none of us need act on our convictions. This useful book would be still better if it had a clearer and stronger moral voice. ■

PAUL ROGAT LOEB is the author of Nuclear Culture *(New Society Publishers),* Generation at the Crossroads *(Rutgers University Press), and the forthcoming* Soul of a Citizen *(St. Martin's Press).*

A BONE TO PICK

"A Window on Arthritis" (*MIT Reporter, TR October 1996*) by David Brittan claims: "If you can walk, bend an elbow, or flex your fingers without debilitating pain, you have proteoglycan to thank. This is the gel-like material that gives cartilage 90 percent of its stiffness." In making the only measurements of the stiffness of human cartilage in vivo, my research group has found that joint stiffness is due primarily to the pressurized fluid in the cartilage, not proteoglycan. When a person walks, the highest cartilage pressure is 750 pounds per square inch (psi). When he or she rises from a low chair or descends steps, the pressure can approach 2,800 psi. Because the proteoglycan contributes less than 150 psi to cartilage stiffness in these instances, its role in joint support is very small. Instead, the proteoglycan is vital in reabsorbing the fluid squeezed out of the cartilage by joint loading. We can thank this pressurized fluid for supporting the joints and precluding arthritis, which occurs when bone rubs on bone.

ROBERT W. MANN
Whitaker Professor Emeritus
Biomedical Engineering
MIT



WHAT COMES UP...

The January 1997 issue of *Technology Review* ironically contains managing editor Sandra Hackman's "Winning through Cooperation: An Interview with William Spencer," head of Sematech, and Jacob Park's book review of Scott Callon's *Divided Sun: MITI and the Breakdown of Japanese High-Tech Industrial Policy*. Sematech and MITI are large, government-sponsored consortiums of semiconductor manufacturers. However, while Sematch thinks that it has not reached its growth peak, MITI has passed its heyday and is now in decline and disgrace. I believe that Sematech will follow MITI's path. A descent would have nothing to do with national policies; it is simply inevitable.

We should remember that most of today's successful large companies were once small; they prospered and expanded because their competitive nature was healthy and conducive to growth. Sematech started out big and will remain that way only as long as it continues to make winning decisions. However, since Sematech has never faced a competitor, except for MITI, it has yet to learn how to fend for itself.

To stay ahead, the United States needs many small businesses in competition, instead of one large firm or consortium, such as Sematech, deciding on *the* approach for the industry and the country. MITI exerted this type of influence in Japan and, owing to some bad politically motivated decisions, led that country to its decline in the semiconductor industry.

LYDON S. COX
Address Withheld

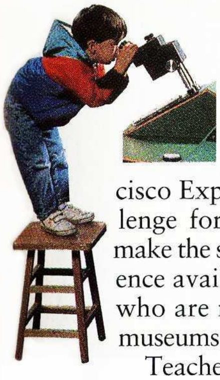
THE ECONOMICS OF CHILD LABOR

The problem of childhood labor discussed by Langdon Winner in "The Destruction of Childhood" (*TR November/December 1996*) could be alleviated by financially supporting all the world's children so that they could attend school instead of working. However, since a child's job is often a major financial component of an entire family's survival, the family would also have to be subsidized. Here we go with a global welfare system. Before sounding the trumpet of the righteous, Winner should have considered that the United States passed laws against child labor only after it could afford to do so.

WILLIAM G. DENHARD
Reading, Mass.

LESSONS FROM SCIENCE MUSEUMS

Anyone who has spent significant time in science museums must echo Larry Bell's assertion in "Scientist for a Day" (*TR February/March 1997*) that they offer a rich form of informal education. Indeed, many of the researchers I know attribute their initial engagement with science to time spent during their youth



at New York's Museum of Natural History or the San Francisco Exploratorium. The challenge for U.S. educators is to make the science-museum experience available to those children who are not regularly taken to museums.

Teachers and administrators also need to think of science museums as resources on which they can readily draw. First, they must feel comfortable at museums. Second, they should be able to absorb lessons from the installations and museum guides' explanations, and try to utilize or adapt them in the classroom.

Science-museum staff also need to prepare and update their exhibitions according to the local, state, and national educational standards that are emerging in the sciences and mathematics. To the extent that exhibits can be tied to these standards, educators (and parents) will find them of great interest and help. If, however, museums develop exhibitions that do not in some way incorporate the new standards, then their often elegant wares will continue to speak only to a small privileged group, rather than to the nation's children.

HOWARD GARDNER
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Cambridge, Mass.

I heartily agree with Bell that the only way to engage children's interest in science is with hands-on experimentation. As the mathematician Jules-Henri Poincaré said about a century ago: "Just as houses are made of stones, so is science made of facts; but a pile of stones is not a house and a collection of facts is not necessarily science."

In most U.S. elementary schools, studying science is equated with memorizing facts. This approach is dry and boring and eventually turns children away from science. When children become involved in doing things, however, their curiosity is peaked and they gain scientific skills and knowledge in the process.

AVI ORNSTEIN
Educational Director
Little Scientists
Ansonia, Conn.

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